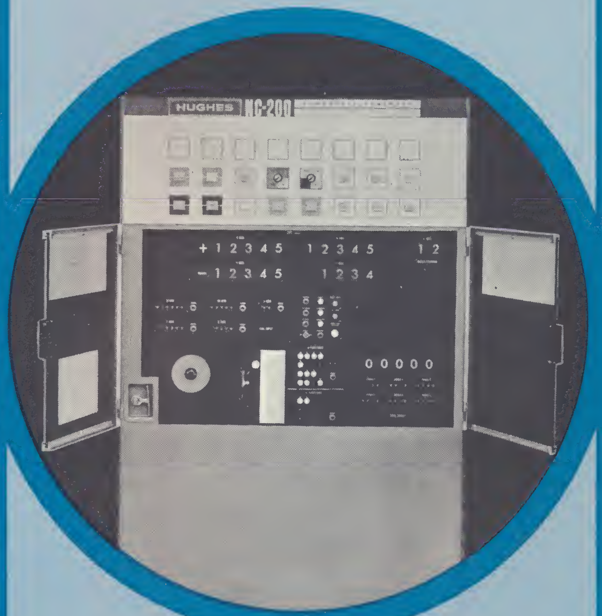
HUGHES NUMERICAL CONTROLS

an
extension of
management
control
to . . .

REDUCE COSTS,
INCREASE PRODUCTION,
IMPROVE QUALITY . . .
WITH RELIABILITY



Creating a new world with ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY
INDUSTRIAL SYSTEMS DIVISION

HUGHES NUMERICAL CONTROLS

. . . are reducing production costs for industrial users **for the METAL-WORKING INDUSTRY**

. . . and HUGHES NC-200 Series Numerical Controls bring to industrial management an even greater tool for cost control

The thousands of metal-working machines throughout the world now being operated with numerical controls are giving their users higher production rates, improved product quality, reduced scrap, lower tooling costs, smaller product and tooling inventories, longer tool life and many other profitable advantages.

Many improvements in the field of machine tool control have been made during the few short years that numerical control has been available. Today's concept and application of numerical control has elevated metal-working machinery to a new level of automated productivity with tremendous savings to the manufacturer and his customer. Numerical control puts all operator orders on a simple punched tape: X-Y-Z axis positioning of the work and tool, tool changes, feed, speed and cycle selection.

The advantages of numerical control are expanded even further with the HUGHES NC-200 Series Numerical Controls, representing ten years of development and use by hundreds of metal-working plants:

- increased productivity
- faster programming
- simpler operation
- design compatible with nearly any production metal-working equipment and machinery requiring positioning straight cuts or punching in controlling:

DRILLING MACHINES
HORIZONTAL BORING MILLS
PUNCH PRESSES
TURRET LATHES
MILLING MACHINES

. . . and, these two and three axis numerical controls can also be used with spot welders, tube benders and other specialized metal-working equipment. Hughes NC-200 Series Numerical Controls require a minimum of floor space and are efficiently integrated with a wide range of types and sizes of machine tools. The real extent of these special applications and adaptations is a function of the ingenuity and vision of manufacturers . . . and the support of Hughes' applications engineers.

Hughes NC-200 Series Numerical Controls . . .

are now working as an efficient management tool, and are used to extend management control more effectively into the production area to reduce costs, to insure sustained product quality, and to increase production speed and volume.

EFFICIENT PACKAGE DESIGN . . .

to insure maximum operator utility, easier operation, faster maintenance and less down time, with features to permit visual check of input data, manual inputs for custom and semi-automatic operation, and other important time saving advancements.

INCREMENTAL PROGRAMMING . . .

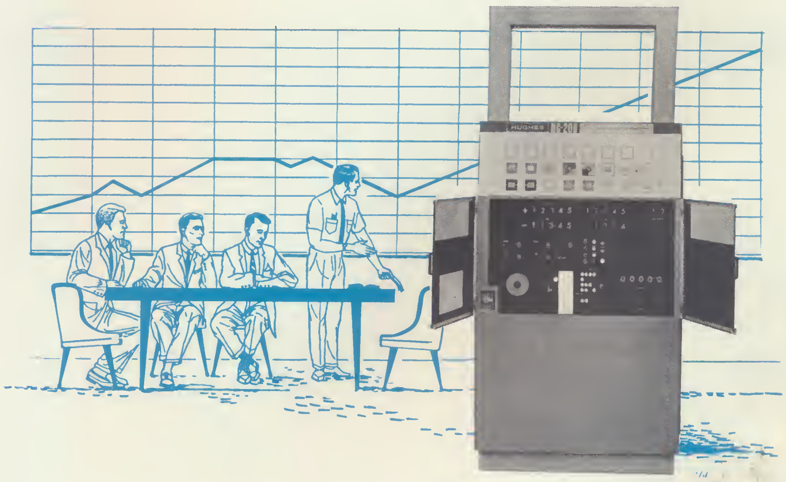
simplest and least expensive of all types of programming in use today — done from conventional engineering drawings without the need to change drafting practices, and — the only type of programming capable of using advanced digital control techniques to their fullest extent for greatest productivity.

SOLID STATE ELECTRONICS . . .

with an extra safety margin built in to eliminate extensive down-time due to component failure. The NC-200 Series Numerical Controls will operate under relatively more severe temperature and humidity conditions than machines they control . . . and, without air conditioning equipment.

FAST ORIENTATION . . .

no need to teach or learn new and intricate procedures, advanced mathematics, tool set-up methods or drafting practices. Without major production interruption, the Hughes NC-200 Series Numerical Controls are placed into operation smoothly and begin producing profit dollars fast.



Technical Information
Hughes NC-200 Series Numerical Controls

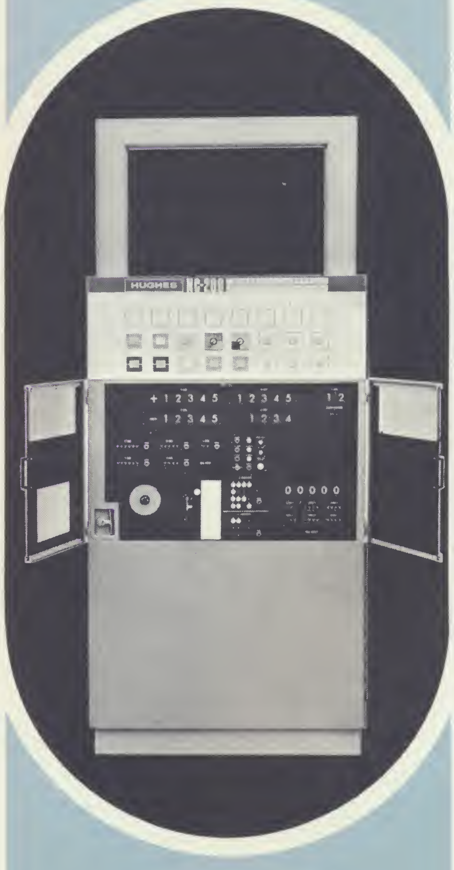
HUGHES NUMERICAL CONTROLS

an extension of engineering design control into production to ensure

DESIGN CONFORMANCE
HIGHEST PRODUCTIVITY
QUALITY CONTROL

- SIMPLEST PROGRAMMING
- SHORTEST PROGRAMMING TAPES
- MINIMUM SERVICE AND MAINTENANCE
- EASIEST OPERATION
- COMPLETELY SELF CHECKING . . .

  at the manuscript stage
  at the machine



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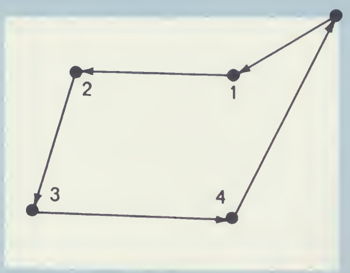
INDUSTRIAL SYSTEMS DIVISION

WHY INCREMENTAL PROGRAMMING ?

Incremental programming cuts inspection time by 90%!

Just start and end each tape program at a fixture reference or a setup hole zeroed to the machine spindle. Indicate the reference hole — that is all the inspection needed. Since the sum of all moves equals zero, any positioning error will show up immediately.



	X
Hole 1	+ 00.500
Hole 2	+ 00.820
Hole 3	+ 00.180
Hole 4	— 01.000
Home	— 00.500
	± X = 0.

No matter how your drawings are dimensioned, the Hughes incrementally programmed N/C system provides for easy self-checking by the "add up to zero" method. Transpositions are caught; wrong callouts prevented.

- *simpler part programming — 50 to 75% less programming time*
- *less complex manuscript preparation*
- *self checking for assurance of accuracy — as much as 90% reduction of inspection times*
- *easy manual data insertion for changes of machine position, start point, custom variations and checking*
- *full floating zero*

RESULTS:

Less cost, less operational expense, less complex operation . . . and assurance that produced part reflects all the features of the engineering design.

Metal-working machinery operates incrementally — from one point to another. Logically then, the Hughes NC-200 Series Numerical Controls use **incremental** programming — point-to-point measurements — to get machine tool positioning devices from one point to another with a high degree of accuracy. Incremental programming employs digital mathematical language, the world's most widely used computation and control media. Hughes Incremental Systems do not accumulate errors.

Incremental programming is a means of planning the production of machined parts in the same manner in which the machine tool will make the parts — incrementally. The starting point is a reference point on the part or fixture selected by either the programmer during the programming stage, or by the machine operator after the part is placed on the machine tool for production. Instructions begin at this starting point (or "home"). The instructions in the program direct the process to the next point, command the corresponding operation, proceed to the next point, operate again, etc., until the part is complete to the extent of that programmed operation series. Incremental programming can end with a "return to start" command to verify that the work positioning elements return to the exact starting point, ensuring that the machine and tape operated accurately — a self checking inspection feature of the Hughes NC-200 Series Numerical Controls. Return to the same position from which it started proves the programming and machining accuracy because the algebraic sum of all incremental movements must equal 0. No other programming system has this exclusive feature.

WITH INCREMENTAL PROGRAMMING, the "return to start" means that ALL operations were accurate per the tape instructions. With ABSOLUTE programming systems, the work positioning table coming "home" **only** verifies that it has responded to a command to come "home," nothing more. Absolute-programmed numerically controlled systems depend upon an arbitrary reference point, usually external and remote from the part being produced. All dimensions are referenced back to that point during each instruction and operation. Replacing a part upon the work positioning table, and achieving exact register, is thus highly critical, time consuming, expensive and, if not exact, results in an inaccurate part. Hughes made the right choice when, over five years ago, the design engineers working on the NC-200 system decided that the INCREMENTAL programming concept had the greatest potential value to all future users of numerically controlled machine tools.

HUGHES NC-200 SERIES NUMERICAL CONTROLS

PROGRAMMING

Programming for machines using the Hughes NC-200 series controls is simple. Existing personnel with knowledge of shop practices can be trained in less than one week. Standard typewriter type tape operation equipment is used. It is not necessary to make special drawings. The programmer plans his manufacturing sequence, selects tools, and describes the part holding method. He then lists his coordinate locations for each operation on the manuscript and adds the code for proper feed, speed and machine functions. The completed manuscript is then given to a typist for preparation of tape. Average total programming time, including sequencing, manuscript writing and preparing the tape is less than three minutes per hole.

Miscellaneous or "m" functions are provided to control coolant flow, initiate special features such as fixture index, automatic clamps and to rewind tapes or delay operations for inspection or other purposes.

An example of a program illustrates the simplicity of the total operation: A complete range of preparatory or 'g' functions (see Table) are available for the programmer to define the spindle cycle (drill, mill, tap or bore) to establish the level to which the tool should retract after machining, to activate productivity-increasing functions such as free z and elimination of slow-down at the bottom of a hole. Each type of function remains active till superseded.

TABLE OF g FUNCTIONS

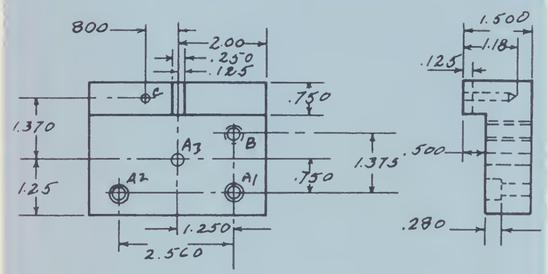
g-60	Top retraction	g-68	Inhibit feed - ON
g-61	Selective zero or 'r' retraction	g-69	Table retract
g-62	Surface retraction	g-80	No cycle (milling)
g-63	Inhibit creep - OFF	g-81	Drill cycle
g-64	Inhibit creep - ON	g-82	Drill w/dwell cycle
g-65	Free z - ON	g-84	Tap cycle
g-66	Free z - OFF	g-85	Bore cycle
g-67	Inhibit feed - OFF	g-89	Bore w/dwell cycle

HUGHES NC-220 SERIES PROGRAM SHEET

Sheet 1 of 1

PART NO. 750621

Operation description	Block No. ooonooo	goo	X Axis x±ooooo	Y Axis y±ooooo	Z Axis zoooo	F.R. foo	wooooo	roo	S.S. soo	Tool too	moo
ALL AXES HOME	ooon 001	g 69									
SET CYCLE	ooon 002	g 81									
SET RETRACT	ooon 003	g 62									
FREE Z ON	ooon 004	g 65									
DRILL 17/64 A1	ooon 005	g 63	x+09500	y+06500	z 1100	f 40	w03500		s08	t 01	m 08
DRILL 17/64 A2	ooon 006		x+02560								
DRILL 17/64 A3	ooon 007	g 60	x-01310	y-00750							
CREEP ON	ooon 008	g 64									
SET RETRACT Y	ooon 009	g 61									
FREE Z OFF	ooon 010	g 66									
C'BORE A1	ooon 011	g 82	x-01250	y+00750	z0280	f 40	w01000	r02		t 02	
C'BORE A2	ooon 012	g 60	x+02560								
CREEP OFF	ooon 013	g 63									
FREE Z ON	ooon 014	g 65									
DRILL 5/16 B	ooon 015	g 81	x-02560	y-01375	z 1200	f 40	w01000			t 03	
TAP 3/8-16 B	ooon 016	g 84			z 1200	f 14	w01000		s03	t 04	
SET RETRACT Y.	ooon 017	g 61									
DRILL 1/8 C	ooon 018	g 81	x+02050	y-00745	z0500	f 30	w00500	r03	s08	t 05	
DEEP HOLE	ooon 019				z0380		w01000				
DEEP HOLE	ooon 020	g 60			z0300		w01380				
CREEP ON	ooon 021	g 64									
POS. TO MILL	ooon 022	g 80	x-00800	y00550	z0125	f 99	w00500			t 06	
MILL SLOT	ooon 023			y+01350		f 11					
MILL OFF	ooon 024	g 81									m 09
X & Y AXES HOME	ooon 025	g 69									m 29



A1	DRILL 17/64 DIA THRU
A2	" " " "
	C'BORE 25/64 DIA x .280 DP
A3	DRILL 17/64 DIA THRU
B	DRILL 5/16 DIA THRU
	TAP 3/8-16 NC-2B FULL THR'D
C	DRILL .125 DIA x 1.18 DP

INCREMENTAL PROGRAMMING REQUIRES NO CHANGE IN STANDARD DRAFTING PRACTICES!

NUMERICAL CONTROL does not necessitate special dimensioning on production drawings for programming procedures. The Hughes NC-200 Series Numerical Controls use a programming manuscript prepared directly from conventional engineering drawings — no new drafting room procedures are required. Any drawing — with incremental or absolute dimensioning — of a quality and format sufficient for the production of a part by the manual method is adequate for the programmer's use in preparing a manuscript for incremental programming.

ADVANTAGES FOR SPECIAL PARTS . . . with incremental programming. Repetitive hole patterns — just define the corodinates for the pattern plus the move to the starting point of the next repeated pattern. The tape puncher can either repeat the pattern as many times as necessary, or punch in a tape rewind, so that the pattern is repeated automatically. Example: A turret drilled part with 10,000 holes in a matrix pattern required only three lines of manuscript, plus three lines of typing and machine operator instructions. The tape preparation took 29 minutes. That is INCREMENTAL programming at work.

MULTIPLE SETUPS . . . ONCE the part is programmed, a repeat command is added along with a new start point, and another example of INCREMENTAL programming simplicity is evident.

MIRROR IMAGE PARTS . . . ONCE a part is programmed, simply reverse the sign of each dimension in ONE coordinate to make the mirror image program. A brief note from the programmer, on the manuscript, to the typist is all that is required to again demonstrate the simplicity and versatility of INCREMENTAL programming.

OPERATING CONVENIENCE and SIMPLICITY

and

A WIDE RANGE OF MODELS

to satisfy a variety of applications . . . and projected costs

In 2 typical examples:

- **FAST TAPE LOADING . . .**
  takes less than 10 seconds — no manual engagement of sprocket holes, no takeup reel to thread or install. A punched code at the end of the tape signals the tape reader automatically to rewind the tape, or rewind can be manually selected. The Hughes high-speed photoelectric tape reader ensures longer tape life, reads at the rate of 60 rows per second. Loop tapes can be used for specialized high-production applications.

- **CONVENIENT CONTROLS . . .**
  all controls are placed on the front panel of the Hughes NC-200 Series Numerical Controls for maximum operator visibility and efficiency. Data storage information lights display **all** information being taken from the program tape for each row as it passes under the photo-electric tape reader, providing a simple, direct means for checking programs and trouble shooting the equipment. Provisions are available for manually dialing all information into the numerical control for semi-automatic or tape override operation.

- **"ALL STOP" CONTROL SAFETY**
  an "All Stop" button is provided to stop all movements immediately without loss of stored information in the event of emergencies. After the cause for stopping has been relieved, the command to proceed from the stopped position may be given without loss of continuity or accuracy.

- **COMPLETE CONTROL PROVISIONS . . .**
  are available for full automatic, semi-automatic, block-at-a-time and jogging operations as well as the complete control of the machine tool at the numerical control console.

NC-221

Lowest cost 2 axis control

NC-223

3 axis, spindle control

OPTIONAL FEATURES —

The NC-221 and 223 models are available with a wide variety of optional features to further extend management control. These options include:

- Tool offset to permit use of random length tools or to compensate for tool wear. Simple setup, requiring only the manual movement of the machine spindle until the tool contacts the work and then the dial entry of displayed data for each tool.
- Programmed speed rates for machine spindles and feed rates for both spindles and work positioning table.
- "Magic 3" speed and feed selections to conform to NAS & EIA Specifications requirements.
- Coolant, air blast and dwell control — plus any other required on-off functions.
- Mirror image control to permit production of left-hand parts from right-hand tapes, or vice versa.
- Programmed sequence number or operation counter.
- Rotary table control to resolution of .01°.
- Feature index function control.
- Tool selection or tool change light.

PRODUCTIVITY

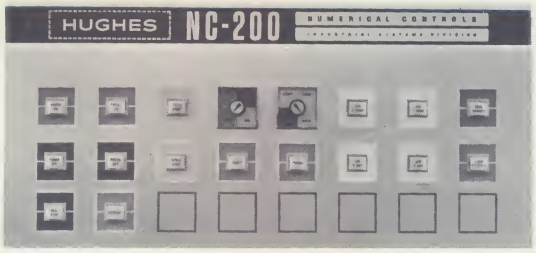
The NC-200 control is built to help users realize the productivity which Numerical Control makes possible. Table positioning is fast with no overshoot or settling time. With the NC-223, full control of spindle functions is provided so that air cutting time can be almost completely eliminated and the programmer can optimize each job by the use of simple-to-use function commands. In addition to the normal "canned" cycles of drilling, tapping, boring and milling, the NC-223 provides for an easily adjustable transition point to start deceleration from traverse to feed rate. The adjustment feature allows each installation to be optimized so that this deceleration distance is the minimum required amount. Deceleration is built into the rapid approach or 'w' axis which means that the feed-rate distance is the hole depth only, not depth plus deceleration allowances. One additional productivity benefit that is derived is that the same tape can be used on machines with different deceleration distances without productivity losses.

Another unique productivity feature is a programmable function called "free z." This permits the tool to advance toward the work while the table is moving into position instead of waiting till table movements are completed. Properly used, this function will save as much as 3 to 4 seconds per hole.

In order to ensure depth accuracy by preventing overshoot, it is customary to slow down the feed rate near the bottom of a hole to a creep rate. However, when the holes being drilled are through holes or where high accuracy is not required, this slow-down requires additional cycle time.

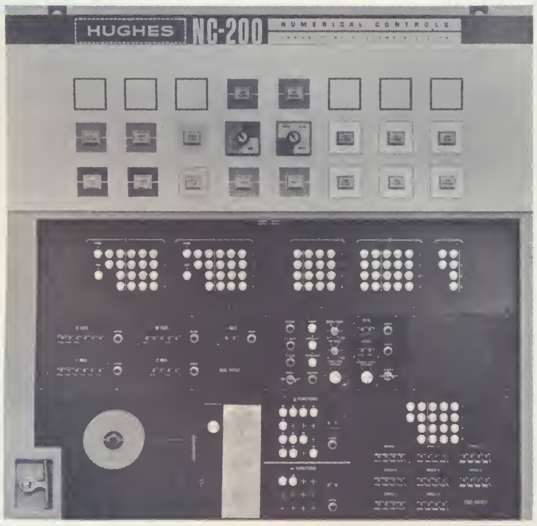
With the NC-223, the programmer can eliminate this creep and thus increase productivity.

A multiple choice of spindle retraction points is offered to minimize air cutting time. The tool can be retracted to work surface, to upper limit, or to a clearance plane. The latter is especially useful where bosses, clamps or part geometry would interfere. The clearance plane is established at a safe level and can be used at the programmer's option.



NC-221

Simplified two-axis control, available with or without manual input. Designed to provide fast, accurate table or part positioning with cycle initiation for low cost drilling and punching machines. Has the same field proven solid state circuits and components as more complex systems. May be modified to permit application to specific types of equipment with the addition of a full range of auxiliary function controls.



NC-223

Most productive three-axis control for application to all types of equipment requiring control of a spindle axis. Available with a full range of options and auxiliary function controls, with displays and manual inputs for all controlled axes and functions. Features automatic cycles and programmable functions designed to greatly minimize air cutting time.

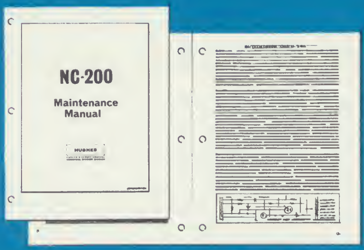
NC-200 =
an extension of
management and engineering
control

Creating a new world with ELECTRONICS

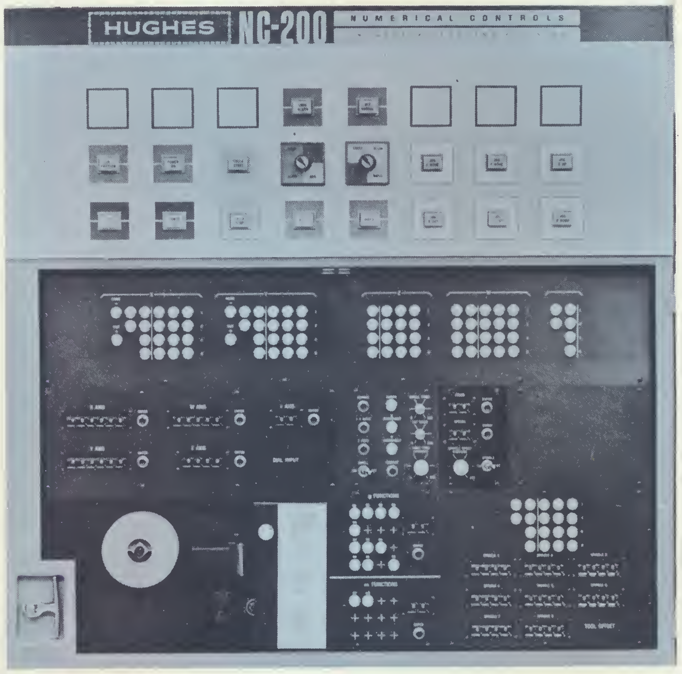
HUGHES

HUGHES AIRCRAFT COMPANY

EASY, FAST MAINTENANCE



designed for quick access . . .
less down time . . .
more production time



Hughes NC-200 Numerical Controls require a very minimum of maintenance — and when maintenance is required, the cabinet design ensures immediate access to any of the internal areas for fast trouble-shooting and repair.

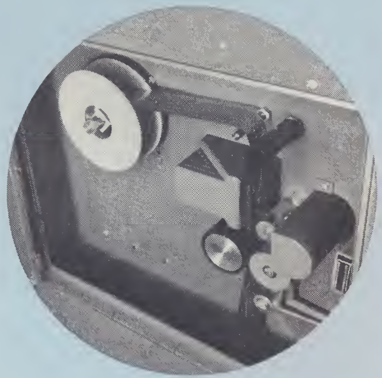
The indicator lights on the front control panel of the NC-200 Series provide an easy means of checking each operation of the equipment. Test tapes can be run through to check out every circuit and operating function of the NC-200. Also, where manual input provisions are included, these buttons can be used to check out the response of the equipment.

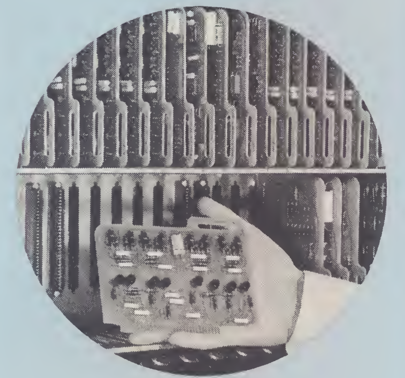
Additional trouble-shooting aids are provided by means of "cause and effect" tables in the Maintenance Instruction Manual furnished with each equipment. No source of trouble, no matter how elusive, should take more than a few minutes to localize.

All access doors and openings are designed to operate lightly and smoothly, and all intercabling is arranged to receive a minimum of wear and not obstruct internal parts and components.

Many of the card modules are identical and interchangeable, a feature which makes practicable "part-trading" as an extra trouble-shooting procedure.

A complete set of blueprints covering all of the functional systems of the NC-200 Series Numerical Controls is provided with each equipment and retained for convenient access on a specially designed binder inside the rear access door. Included are electronic insert schematic diagrams, and system elementary diagrams that indicate system operation and logic and also show physical location of all components.





to make the NC-200
the best tool for the job . . .

The Hughes photo-electric tape reader was especially designed for the Hughes NC-200 Series Numerical Controls, and efficiently satisfies every specific demand — another example of total engineering, and another exclusive feature of the NC-200.

Tape life is greatly extended with a photo-electric reader. Without brushes or contacts to wear the tape or collect dust and dirt, the tape life is nearly infinite and the possibility of mechanical damage is virtually eliminated. Also, the row-by-row reader is fail safe: it continually checks itself to make certain that reading errors do not occur.

SOLID STATE ELECTRONICS . . . are used throughout. All circuits employ highly reliable, heavily safety-margined transistors and diodes.

All circuit components have been selected for their capability to operate reliably for long periods of time under temperature and humidity conditions many times more severe than the anticipated extremes. This intentional design margin and careful component selection has resulted in a numerical control that needs no temperature compensation by air conditioners, nor is the NC-200 design encumbered economically or functionally by the need for cooling devices that serve no purpose other than to offset the inherent design shortcomings of the control system itself. With the NC-200, your dollars buy **CONTROL.**

SOLID STATE SWITCHING CIRCUITS . . . have replaced the use of relays almost entirely in the Hughes NC-200, and the few remaining relays are hermetically sealed, extra long life rated, and plug into receptacles for fast replacement. With the NC-200, your dollars buy advanced design for fast, easy maintenance.

SPECIFICATIONS

Class	Position and straight cut AIA Class III
Type	Digital, incremental
Format	Word address Conforms to EIA Specification RS-273 and AIA Specification NAS 943
Input Medium	1″ wide, 8-channel perforated tape
Tape Reader	Hughes Photo-electric
Reading Speed	60 rows per second
Resolution (.0001 available)	0.001″
Electrical Accuracy	
X & Y Axes	±0.0005″
Z Axis	±.001″
Repeatable Accuracy or Precision (Typical)	
X & Y Axes	±0.0002″
Z Axis	±0.001″
Axis Drive	Electrical or Hydraulic to suit machine requirements
Travel	Unlimited — simultaneous positioning
Speed	As required — up to 250 IPM
Programming Method	Advanced incremental
Power Requirements	117 volt 60 cycle
Dimensions	Model 223: 64″ x 36″ x 28″; Model 221: 57″ x 30″ x 19″
Weight	Model 223: 600 pounds; Model 221: 500 pounds

HUGHES TRAINING, MAINTENANCE, SERVICE . . . ON THE NC-200 SERIES

Hughes training, maintenance data, and field service are designed and provided for maximum utility and service from the NC-200 Series Numerical Controls.

EASIEST . . .
The functional simplicity of the NC-200, along with the comprehensive instructional information provided, makes orientation and training a pleasant experience for the purchaser and his personnel. Users of the NC-200 learn to use it fast . . . and learn to like it even faster. Average training time is approximately 40 hours for complete familiarization, instruction and final checkout.

COMPLETE . . .
The technical documentation package includes maintenance manuals which provide complete theory of operation and maintenance data, trouble shooting tables for average shop personnel, electrical and logic diagrams and point-to-point wiring data. Also, the Hughes Industrial Systems Division personnel in charge of training and field service remain constantly at your service to provide personal assistance should special questions arise at any time.

PROMPT . . .
Field service is prompt and qualified. Hughes Industrial Systems Division field representatives devote all of their time to Numerical Control sales and service. They are on call for technical consultation and aid in any unusual problem areas, and show users the way to extra benefits through the NC-200 Series Numerical Controls. These services include special instruction sessions for attendance by management, engineering, planning and shop personnel.

Inquiries regarding applications of the Hughes NC-200 System and other products of the Hughes Industrial Systems Division are invited. Qualified personnel are anxious to assist you with the simplest or the most complex application.

Creating a new world with ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY

INDUSTRIAL SYSTEMS DIVISION

P.O. BOX 90904
LOS ANGELES 9, CALIFORNIA

PROVEN IN USE

PARTIAL LIST

. . . . of HUGHES NC-200 Series Numerical Controls Users:

General Dynamics/Astronautics
San Diego, California
Motorola
Phoenix, Arizona
Librascope, Div. of General-Precision
Glendale, California
Courtesy Manufacturing
Chicago, Illinois
Rock Island Arsenal
Rock Island, Illinois
Naval Ordnance Plant
Macon, Georgia
McGraw Edison
Pittsburgh, Pennsylvania
Oshkosh Motor Truck
Oshkosh, Wisconsin
International Harvester
Milwaukee, Wisconsin
I.B.M.
Poughkeepsie, New York
Micro Tool and Engineering
North Hollywood, California
Lycoming, Division of Avco
Stratford, Connecticut
Perkin Elmer
Norwalk, Connecticut
Wood Newspaper
Plainfield, New Jersey
Nortronics
Hawthorne, California
Collins Radio
Cedar Rapids, Iowa
Naval Avionics Facilities
Indianapolis, Indiana
General Dynamics - Pomona
Pomona, California
McDonnell Aircraft
St. Louis, Missouri
U.S. Naval Shipyard
Mare Island, California
U.S. Naval Shipyard
Portsmouth, N.H.
H.P.M.
Mt. Gilead, Ohio
Lockheed-Sunnyvale
Sunnyvale, California
Lockheed-Marietta
Marietta, Georgia
I.B.M.
Endicott, New York
Baldwin-Lima-Hamilton
Aurora, Illinois
Tektronix
Portland, Oregon
Clark Bros.
Olean, New York
Creamery Package
Ft. Atkinson, Wisconsin
Caterpillar
Peoria, Illinois
Joy Mfg.
Claremont, N.H.
Union Carbide
Paducah, Kentucky
Aro Corp.
Bryan, Ohio

MAXIMUM APPLICATION . . .
MAXIMUM COST REDUCTION . . .
MAXIMUM PRODUCTIVITY . . .

with the Hughes NC-200 Series Numerical Controls

The PRODUCTIVITY feature of the Hughes NC-200 Series is the most dramatic of all its many advantages. For example, the NC-200 **THREE AXIS** Control has been specifically designed for maximum productivity and simplicity of programming. Reports show that it is 15% more productive than any other system in controlling the spindle axis on a machine, and that the number of separate blocks in a program is reduced as much as 50%.

With the NC-223 Control, the spindle can be advanced towards the work while the table is moving to position. Other systems require that the table be in position before the spindle can advance; result . . . a time loss of as much as 3 to 4 seconds per hole. This is a programmable function called "free Z."

The NC-223 eliminates the need for adding a deceleration distance to the depth of the hole. This is customarily done to provide for transition from rapid traverse rate to feed rate, but on repeat cycles it means that this distance of 2 or 3 tenths of an inch is moved at feed rate. On the NC-223, the deceleration allowance is built into the rapid traverse or w axis and is adjustable for each installation and machining condition. This permits optimizing the machine and reduces non-productive time.

Further increases in productivity are achieved by providing for three modes of tool retraction at programmer's option. He can retract to the work surface; he can retract to the upper limit (as for tool change); or, he can retract to a clearance plane or selective zero position for clearing obstructions such as clamps or bosses. The NC-223 is the only system offering this multiple choice of retraction as a simple function command.

The NC-223 provides a complete selection of "fixed cycles" to describe the action of the cutting tool for drilling, boring, tapping or milling. Hughes NC-200 Series Controls permit the programming of a complete machine cycle in one block of tape. It is not necessary to program table and spindle commands in separate blocks, nor is it necessary to program out of the hole in a separate block.

Where it is not necessary to hold depth to .001" tolerance, such as in drilling through-holes, the slow-down at the end of a feed motion can be eliminated by the programmer. This permits the tool to travel its entire programmed distance at feed rate, thus reducing total cycle time.

With these distinct features the Hughes NC-200 Series Numerical Controls have closed the gap between engineering drawings and finished production parts; and . . . the manufacturer has gained an extension of management control for improving his competitive position and increasing his operating profits.

HUGHES

THE COMPANY

Hughes Aircraft Company is one of the world's largest manufacturers of military and space electronic components and systems. Capabilities and interests range between basic research and development to quality manufacturing, backed up by world-wide field service and technical support.

From the date of the company's inception, Hughes has recognized the increasing demands and importance of lower cost precision manufacturing techniques. Hughes formed the Industrial Systems Division in 1954. The NC-200 Numerical Control System is a product of Hughes advanced engineering know-how resulting from many years experience in the design and development of solid state electronic systems.

FIELD SERVICE
A staff of highly trained Hughes Field Service representatives are located throughout the world to assist users of the NC-200 Numerical Control System. Complete Operation and Maintenance Manuals are provided with each system; factory-trained service engineers are available for instruction, training programs, and service assistance. These services complete the well-rounded program developed for operating and maintaining NC-200 systems, achieving maximum operating efficiency for the user, and assuring maximum product quality.

Inquiries regarding applications of the NC-200 system and other products of Hughes Industrial Systems Division are invited. Qualified personnel are anxious to help with the simplest or most complex application.

CREATING A NEW WORLD WITH ELECTRONICS

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HUGHES AIRCRAFT COMPANY

INDUSTRIAL SYSTEMS DIVISION

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Job Shop Within a Shop

JOHN L. REED
NC Program Supervisor

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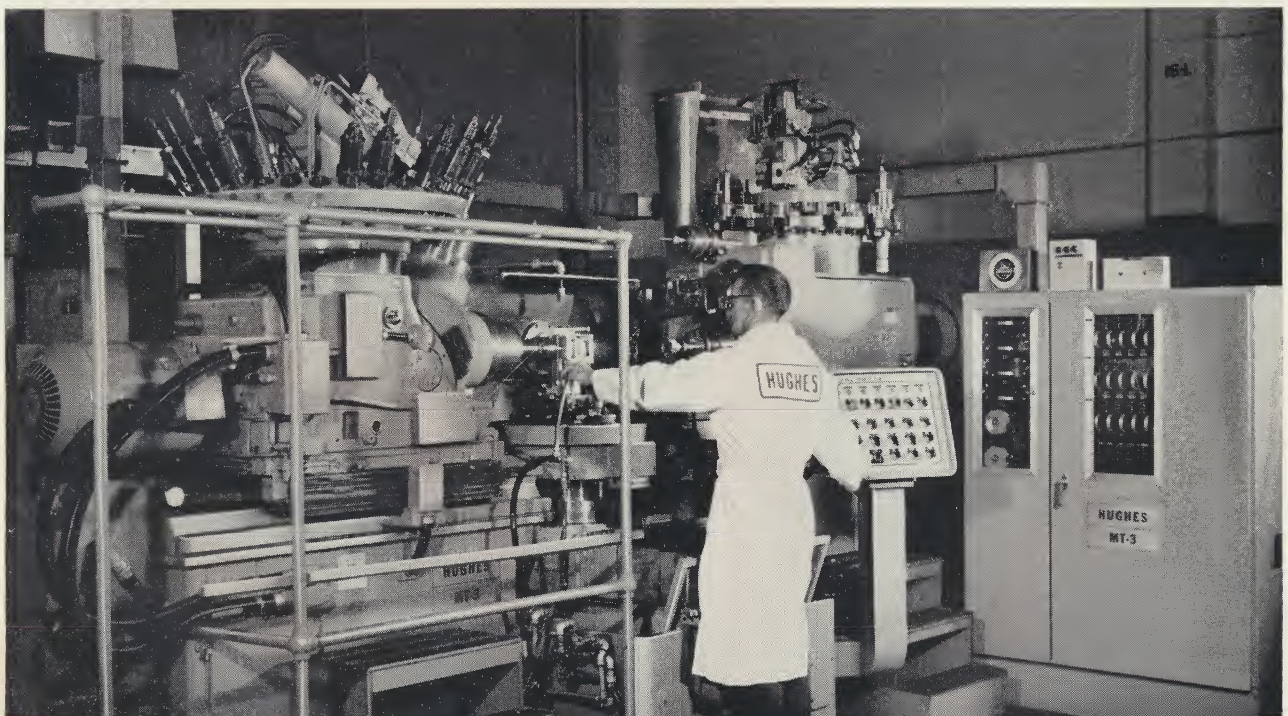
NC Programming Engineer

Hughes Aircraft Co., El Segundo, Calif.

An ideal job shop is one capable of turning out small lots of a wide variety of complex parts at low cost in minimum time. Experience at Hughes Aircraft Co. and elsewhere has shown that its Industrial Systems Division Model MT-3 machining center in many ways meets this definition. In effect, the numerically controlled MT-3 shown in the heading illustration has been found to be "a job shop within a shop" for a broad range of application.

Basically, the MT-3 machining center produces finished parts ready for the assembly line from a programmed tape or a blueprint. It is equipped with a rotary work-table (center, Fig. 1) and a universal head (Fig. 2) with a dual-spindle indexing turret and a thirty-tool capacity changer.

Two additional optional build-



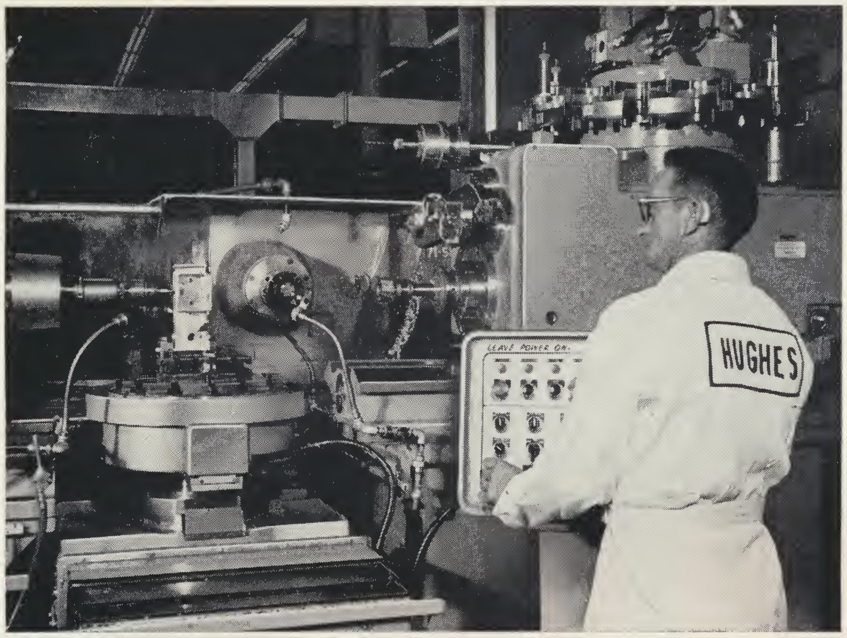


Fig. 1. Close-up view of work area of MT-3 numerically controlled machining center. Part on rotary indexing table is being machined by tool in the universal spindle head at right. Tape program includes operations by heavy-duty milling head at rear and precision boring head at left.

ing-block elements, a heavy-duty milling head and a precision boring head with a fourteen-tool capacity changer, provide for a large number and a wide range of operations on a part. These heads are seen close up at the rear and right of the work-table in Fig. 1. Operations that can be performed automatically in one setup include heavy and light milling, drilling, boring, tapping, and reaming.

Typical parts being produced on the MT-3 by Hughes Aircraft Co., often at manufacturing cost savings ranging from 50 to 75 per cent, are shown in Figs. 3 to 6. In many cases, despite a large number of operations, only a single setup is required. Simple holding fixtures replace the complex tooling ordinarily required and tolerances of a few ten-thousandths of an inch are regularly obtained.

To further reduce fixture preparation time and costs, Wharton tool elements are often used. When machining the complex bracket shown in Fig. 3, Wharton elements are used exclusively, cutting the required tool preparation time to only fifty hours. For conventional machining, 1020 man-hours would be consumed in building the twenty-eight templates and twelve drill jigs required to handle the work.

These brackets are made in ten different variations with changes in over-all length and hole patterns. Although three setups are employed for each part, only three Wharton fixtures are needed to machine all ten different brackets.

The fewer setups and simplified fixtures used permit setup operations to be performed in four and one-half hours instead of the twenty-two hours required to set up for conventional machining.

Except for one honing operation, these parts are produced complete to blueprint sizes in three numerically controlled operations. Over 90 per cent of the part, by weight, is removed in machining the brackets from the raw material.

Since three tapes are needed for each of the ten bracket configurations, thirty individual programs and tapes must be prepared. All three heads of the MT-3 and thirty tools are employed to produce the brackets in an over-all seventy-six-minute machining cycle. Estimated time for conventional machining is four hours. Planning, tooling, and preparing the thirty programs and tapes for the ten brackets required 298 hours, in comparison to 1080 hours for planning and tooling for

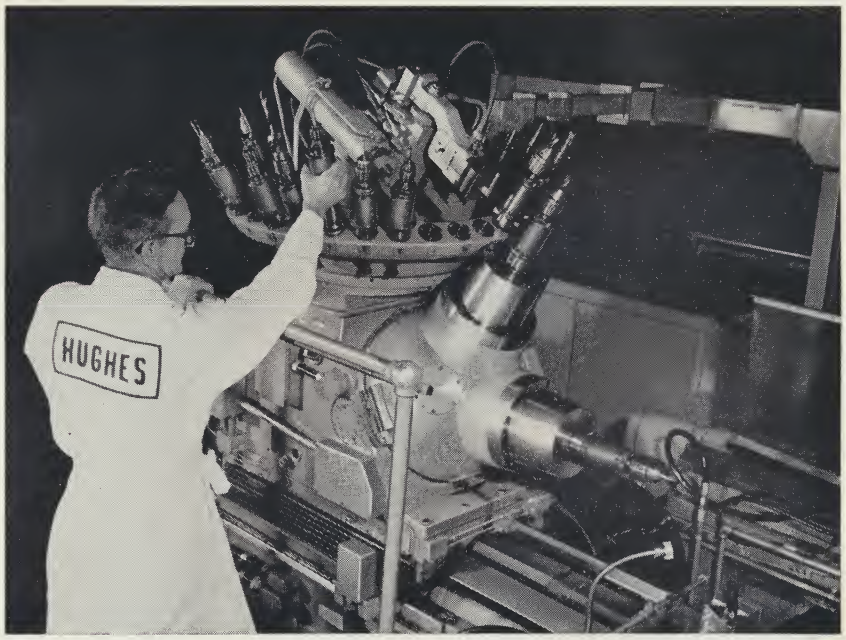


Fig. 2. The universal head is equipped with a double-spindle turret and a thirty-tool capacity changer. While one spindle is operating, the cutter in the idle spindle is changed for subsequent use in the machining cycle.

machining the same parts conventionally.

The first tape is programmed to rough-mill all surfaces and windows, allowing 0.030 inch per side for finishing cuts. These operations remove almost 80 per cent of the work-piece material in a twenty-minute cycle.

In the second setup, three sides, a large window, and an inner pocket are finish-milled; eight holes are drilled, four reamed and four countersunk; and chamfers are cut on the outer periphery. This cycle removes another 6 per cent of the original material and requires about eighteen minutes. The third tape directs the finish milling of four outer surfaces, the inner contour, three pockets, and a small tab. In addition, eight holes are drilled, two bored, one counterbored, and one reamed.

The complex antenna mount, shown in Fig. 6, is also machined by Hughes on the MT-3. Nineteen surfaces are milled at various levels on six sides of the part. In addition, sixty-one holes are center-drilled and drilled, forty of which are counterbored and thirty-two tapped. These operations are performed in two setups requiring two tapes and two holding fixtures. Nineteen cutting tools are used in the universal head and five in the precision boring head.

Planning, programming, and tooling preparation to implement the numerically controlled machining center for this part required 848 hours. This can be compared against 1732 hours for planning and tooling of the same part for conventional machining. Setup time and machining time for MT-3 are three hours and twenty hours, respectively. On conventional equipment, these parts were set up in twenty hours and machined in 6.4 hours.

A single tape and holding fixture are all that is needed to perform fifteen operations on the hose coupling illustrated in Fig. 5. Milling, boring, drilling, and tapping are performed, using only the universal and milling heads. The part is completely machined (except for deburring) in ten minutes, approximately one-fifth the time required for conventional machining. Planning and preparation of tooling, program, and tape were accomplished in eighty-two hours, about one-quarter of the time necessary for tooling and planning for machining the part on standard drilling and milling equipment.

The end block shown in Fig. 6 is completed on the MT-3, except for one tapping and three milling operations. One Wharton holding fixture is used and a single tape program directs machining of the part in twelve minutes. Setup is done in two and one-half hours. Implementation for numerical-control machining required only

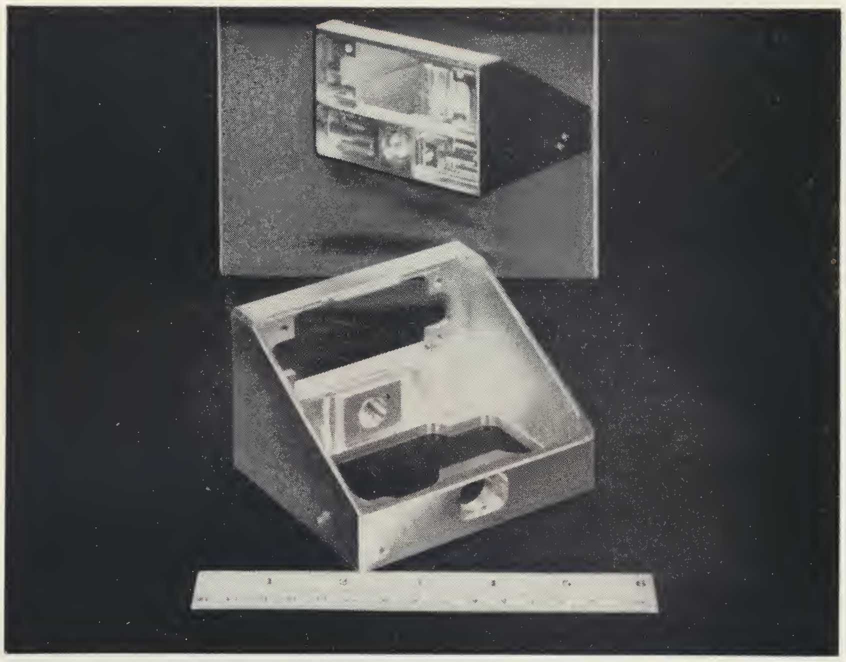


Fig. 3. Only three work-holding fixtures are required to produce ten variations of these brackets. Each part is machined in three setups using three tape programs. Over 90 per cent of original part material is removed in a total machining time of seventy-six minutes.

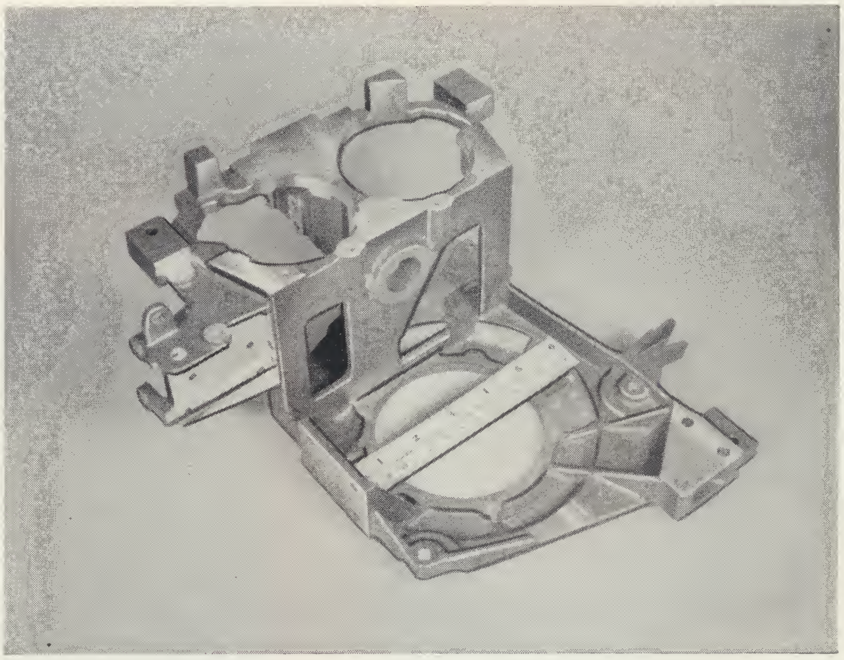


Fig. 4. Complex antenna mount machined using two setups and two tapes. Sixty-one holes are centered and drilled, forty are counterbored, and thirty-two tapped. Ninteen surfaces are also milled. Machining time is eighty-one minutes.

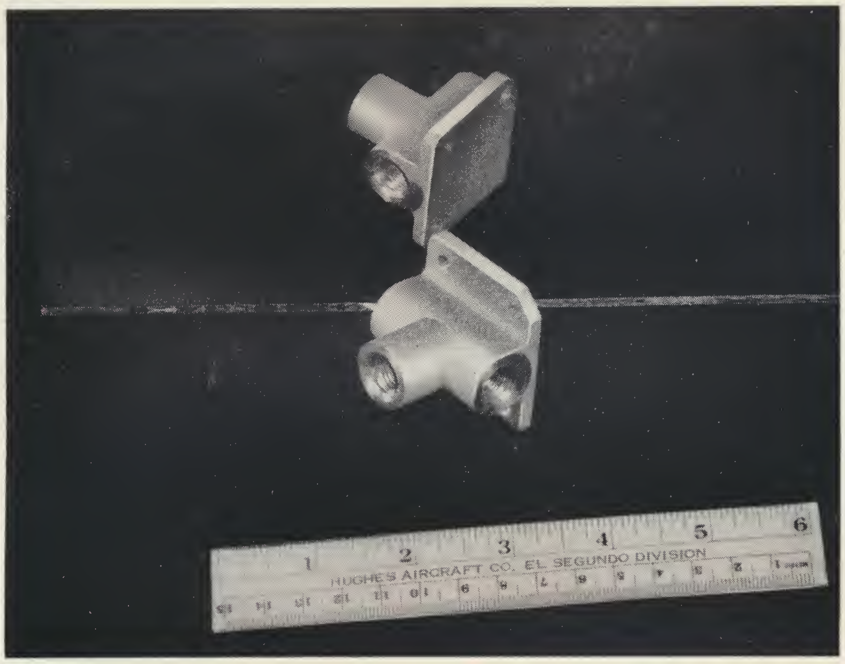


Fig. 5. Only the milling and universal heads are used to complete this component in a single setup. Implementation for numerical-control machining required only one-fourth the man-hours necessary to plan and tool conventional equipment for the part.

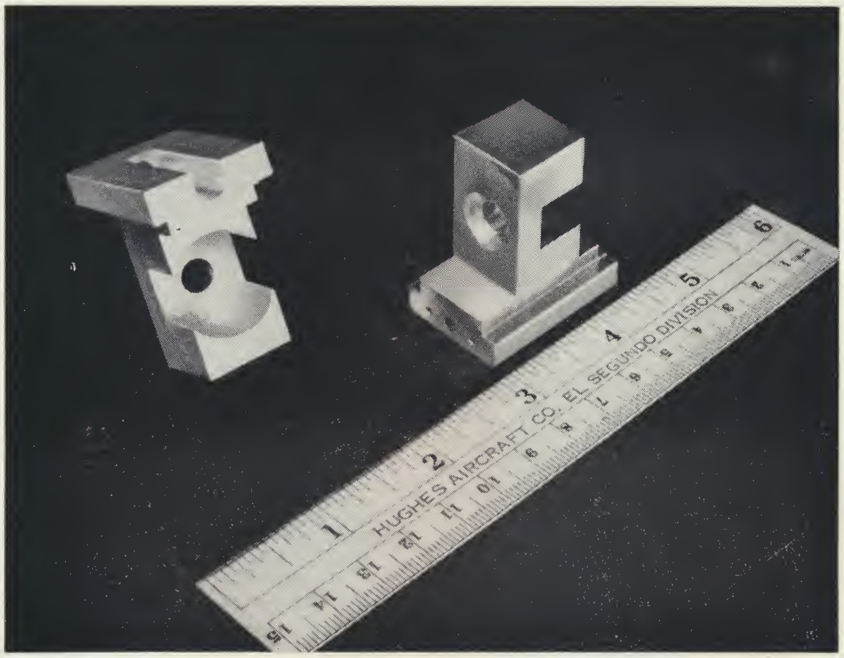


Fig. 6. Another component machined in a single tape program on the MT-3 machining center. Substantial time savings were experienced in actual machining, setup, and overall implementation.

thirty-eight hours. In comparison, planning and tooling for conventional operations took sixty hours, setup required six and one-half hours, and actual machining, fifty minutes. As in the other examples, the time saved in planning and tooling for numerical-control production more than offsets that expended in programming and tape preparation.

The Hughes-designed electronic control system, which incorporates solid-state control circuits and data-handling techniques, is a digital system using incremental planning. It employs E.I.A. (Electronic Industries Association) data coding and uses standard 1-inch wide, eight-channel punched tape.

The photoelectric reader operates at speeds of 200 rows per second, and data-handling time is 0.3 second per block. This eliminates the need for buffer storage equipment. The system is capable of controlling all optional heads, which include a multiple-spindle drill head that will drill up to ten holes at a time for high-production setups.

Simplified programming can be accomplished manually from a "manuscript" prepared from the parts drawing, or computer programming can be used. A special block code is employed which permits tool adjustments to be made during operating cycles.

The machine can be operated manually, semiautomatically, or automatically. In manual operation, all machine movements are initiated at the control panel and the keyboard input on the electronic control unit. In semiautomatic operation, the operator retains control of tape reading and initiation of axes movements, while visual displays allow complete verification of data input to the system. When operated automatically, it is under full tape control, with provisions for the operator to override commands from the tape.

Arrangement of the spindle heads around the work-piece makes it possible to use any one head while another is being made ready. Thirty-one feeds can vary the feed rate of the cutting heads or the work-table from 1 to 75 ipm. A 150-ipm tool approach and retraction rate is maintained until the cutter is ready to enter the work, or has reached its "homing" position.

Although primary advantages of the MT-3 have been found to be in the reduction of tooling and machining costs, other benefits are obtained. These include (1) reduced lead time to produce the first component, (2) smaller in-process parts inventory, (3) minimized parts handling, (4) lower inspection and quality-control costs, and (5) improved management control over the manufacturing process.

AUGUST 7, 1961

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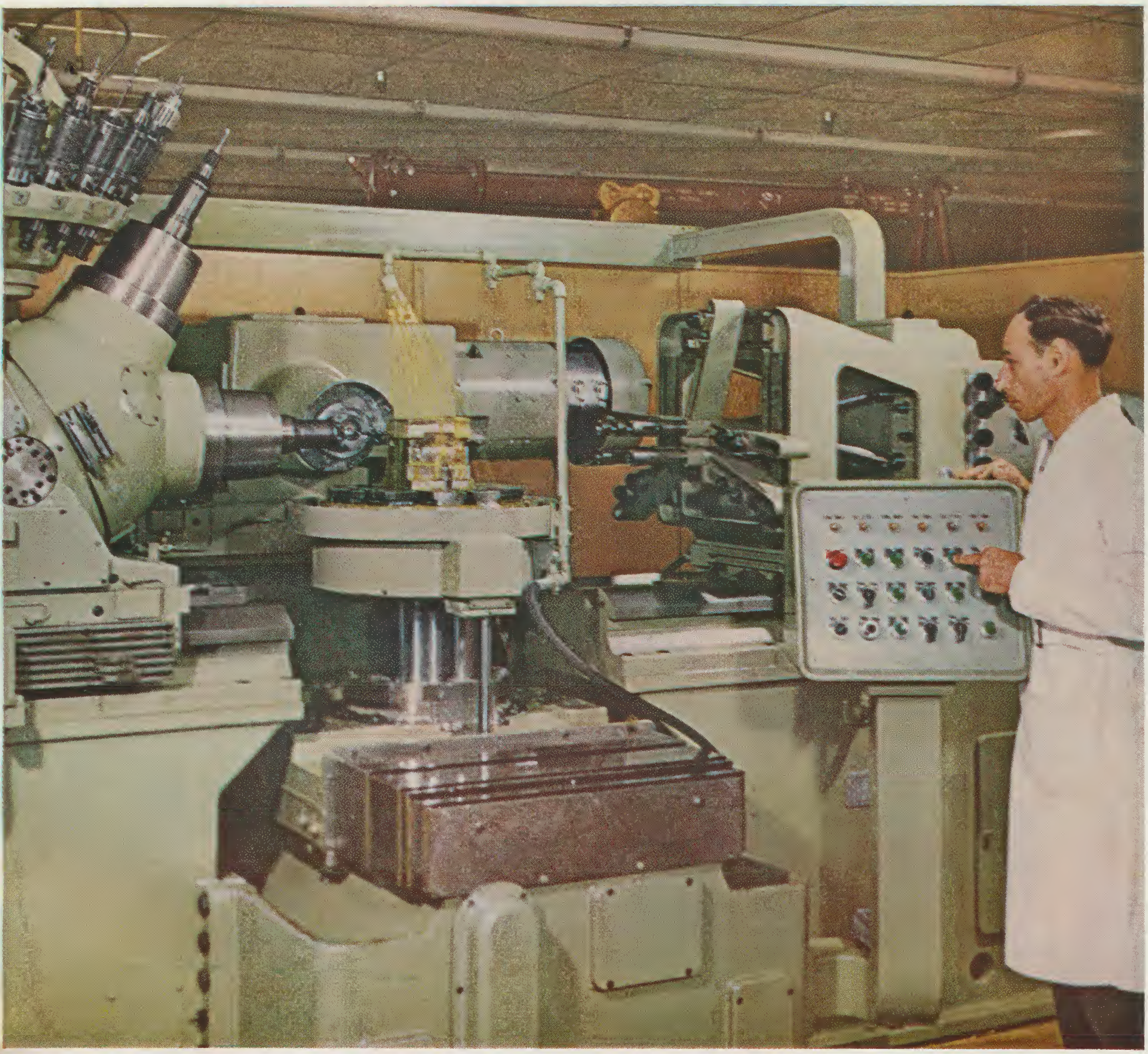
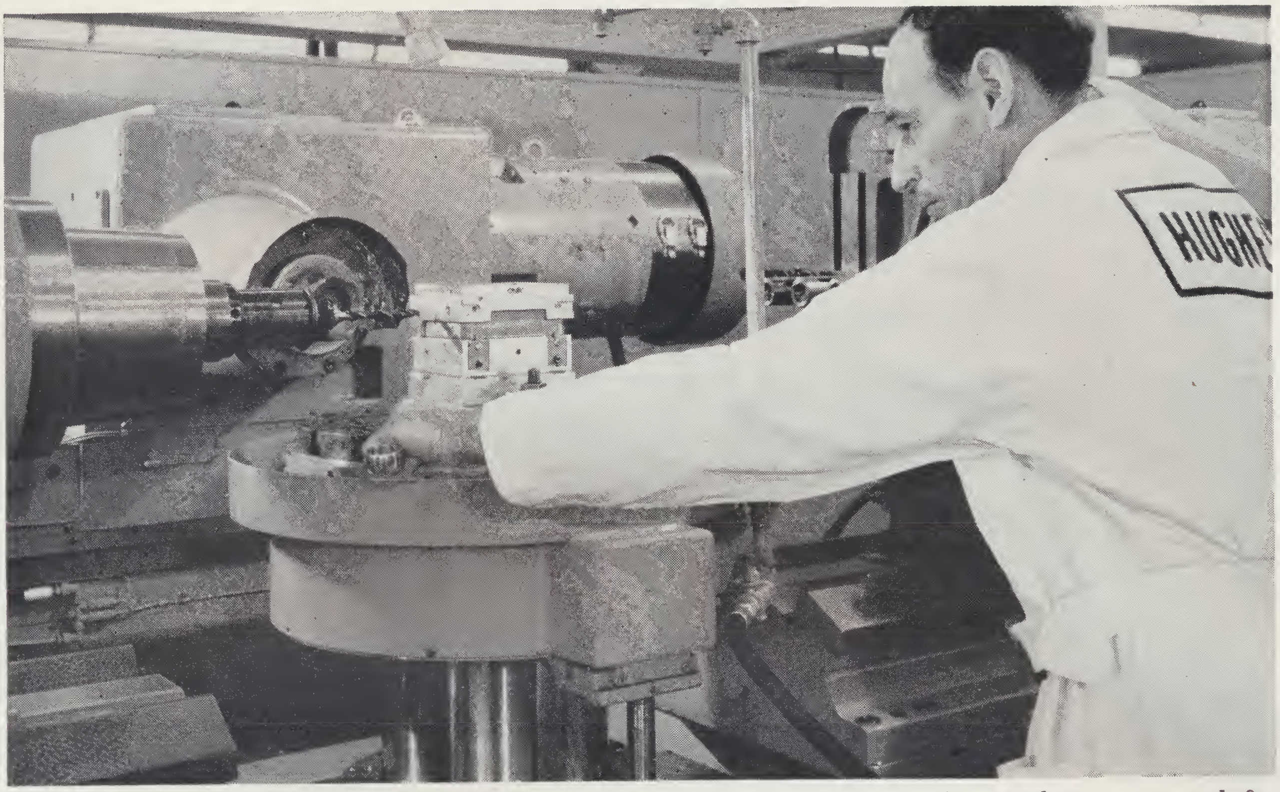


One numerically controlled machine replaces five regular machines



Sixteen separate machining operations are performed on this aluminum sand casting in two setups and one holding fixture on a single numerically controlled machine. Conventional methods required five machines with 11 setups, and five fixtures. Of three heads arranged around the positioning table (drilling, milling, and boring) only two are used.

One machine replaces five

A single numerically controlled "Machining Center" (positioning table surrounded by drilling, milling and boring heads) is doing the work of five machine tools in multiple operations on short runs of complex parts. Costs per part: about 10% that of machining by conventional methods

By George DeGroat
West Coast Editor

Numerical control is really coming into its own at Hughes Aircraft Co, where a single five-axis setup is doing the work of a vertical miller, a six-spindle drillpress, a turret lathe, a boring machine, and a tapper.

Not only that, Hughes' MT-3 "Machining Center" has cut manufacturing time per part from 1 hour to something like 18 minutes.

The Machining Center setup has in fact overcome the sky-high manufacturing costs and low profits that plague shops faced with the job of turning out short runs of complex parts. Here, numerical control has cut down (or even eliminated) the number of jigs and fixtures needed, has reduced setup time to a bare minimum, and has virtually eliminated rejects caused by human error.

Take, for example, an aluminum casting made by Hughes in job lots of 35 pieces—a part so complex in shape that it requires 16 separate machining operations. Among them: milling four sides and the top surface, milling a step in four sides; drilling and tapping 10-32, ¼-20, ½-13 and #2-65 holes; drilling, boring, reaming, and countersinking a variety of holes; end-milling a slot, and profiling openings in the part:

Conventionally, this would require five different machines, plus such tools as a milling fixture, two drill jigs, a holding fixture and a profiling templet. Design time for these tools alone would run 140 hours, and fabrication time another 295 hours.

Nearly 16 hours would be needed for 11 setups, and running time for 35 pieces would be about 24 hours. Manufacturing time per part: a little over one hour.

The same job took only a little over 18 minutes per piece on the numerically controlled setup. And only two fixtures were needed (design time 32 hours and toolmaking time 56 hours for the two). Running time for performing the 16 machining operations came to slightly under 10 hours for the 35 pieces.

One setup for many jobs

The five-axis numerically controlled Machining Center, developed by Hughes' Industrial Systems Division, is designed to handle a variety of operations in a single setup.

The unit has three tape-controlled work heads (building-block construction) arranged around a central positioning table. One of these is a universal drilling, tapping, and boring head with storage capacity for 30 tools up to 3½ in. diameter. A tool turret at this head changes tools

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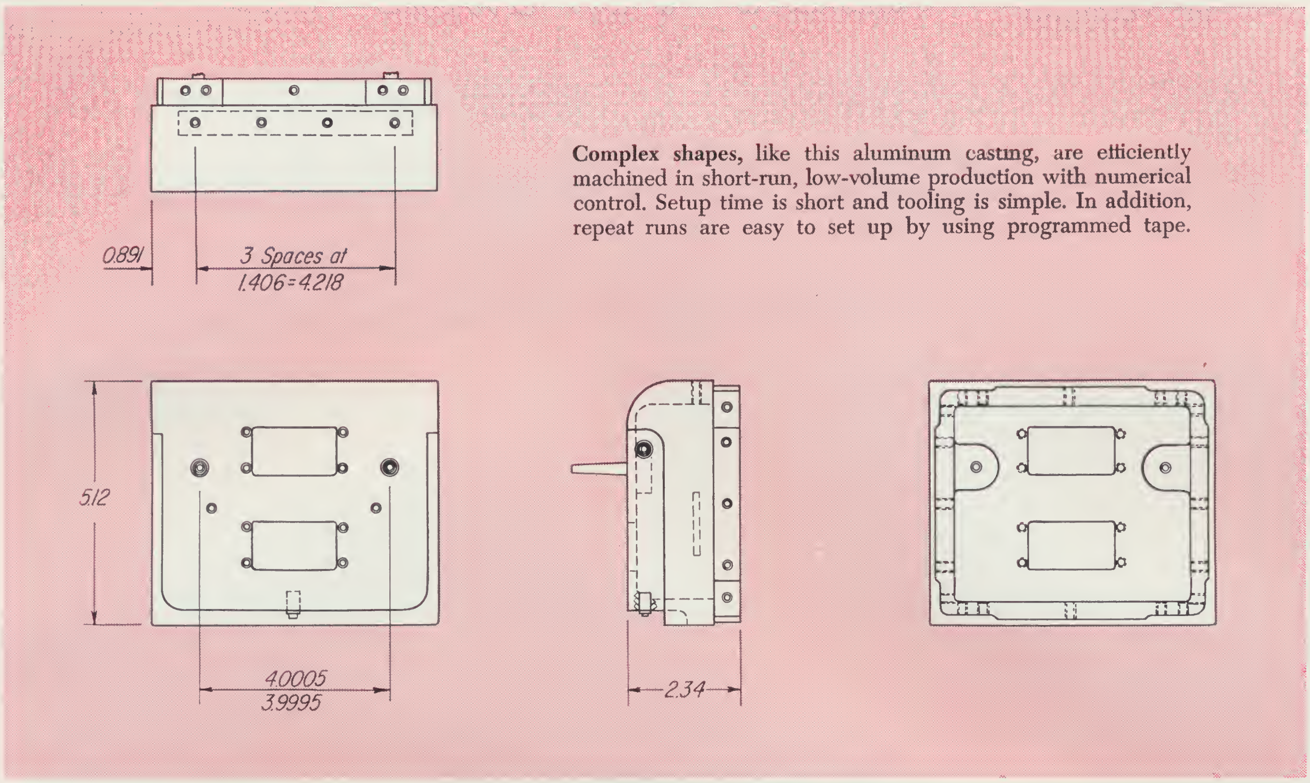

Complex shapes, like this aluminum casting, are efficiently machined in short-run, low-volume production with numerical control. Setup time is short and tooling is simple. In addition, repeat runs are easy to set up by using programmed tape.

automatically in accordance with programmed instruction in less than 3 seconds, while a dual-spindle arrangement at the head allows one table to be transferred to and from one spindle while the other is at work.

Tools are selected by tape commands, which position the rotating magazine—lifting the stored tool from the turret and into a ready spindle. A hydraulic cylinder moves the tool. Similarly, tools are removed from the spindle and returned to storage.

3-second tool change

At the end of the operation, the dual-spindle mount rotates 180 degrees, bringing the new tool into working position. It takes only 3 seconds to change and position a tool.

For example, drilling and reaming can be done on a series of holes simply by rotating the spindle at each location, rather than drilling all the holes and then reaming them.

A milling head behind the positioning table handles cutters up to 8 inches in diameter and has 28 speeds from 60 to 2400 rpm.

The third head, for precision boring, has 21 speeds from 100 to 3000 rpm, is also equipped for automatic tool changing and can handle up to 14 tools of 1-6 in. dia.

Operation of Hughes' Machining Center is automatically controlled from 1-inch punched tape, from which machining instructions are read by a tape reader. The electronic numerical control system provides for point-to-point positioning in increments of 0.001 in. through velocity servos.

Taped data is delivered from the reader through a distribution system to an axis buffer storage. Here, the information is held until the beginning of a machining operation is called for by the start command or by a completion signal from the previous machining operation.

Planning and programming the Machining Center requires no special skills or auxiliary equipment. First, the sequence of operations and the method by which the part is to be held must be determined. Then data is entered on a planning sheet, including: operation number, machine head number, direction of movement; dimensional movement along head, cross and vertical axes from their previous positions; spindle speed, feed rate, tool selection, table position and direction of rotation, and any special tapping cycle that may be required.

Preparation of parts manuscripts is handled by manufacturing engineering personnel, who work directly from the part drawing.

Planning and programming a manufacturing outline for a fairly complex stainless steel part, for example, takes about 40 hours, as opposed to only 16 hours for doing the job by conventional methods. But in the long run (taking the entire operation into consideration from planning to finished part), it costs about a tenth as much to produce the part on this numerically controlled machine as by conventional methods.

Another case history

As in the previous example, lot size was 35 pieces, and five machines were needed for conventional operations, plus such tooling as two milling fixtures, two lathe fixtures, and a drill jig. Conventional tool design time was 286 hours, and toolmaking time 572 hours. Nine setups were required for the five machines (14.3 hours' setup time in all), and running time for the 35 pieces was 97.2 hours.

Eleven separate machining operations included milling a flange face in four places, boring, drilling, tapping, and spotfacing.

By contrast, the numerically controlled setup required only one holding fixture, which took 16 hours to design and 36 hours to build. The one needed setup took just 2 hours, and running time was only 11.8 hours. Net result: 3.188 hours per part by conventional methods, 0.339 hour per part with the new setup. •

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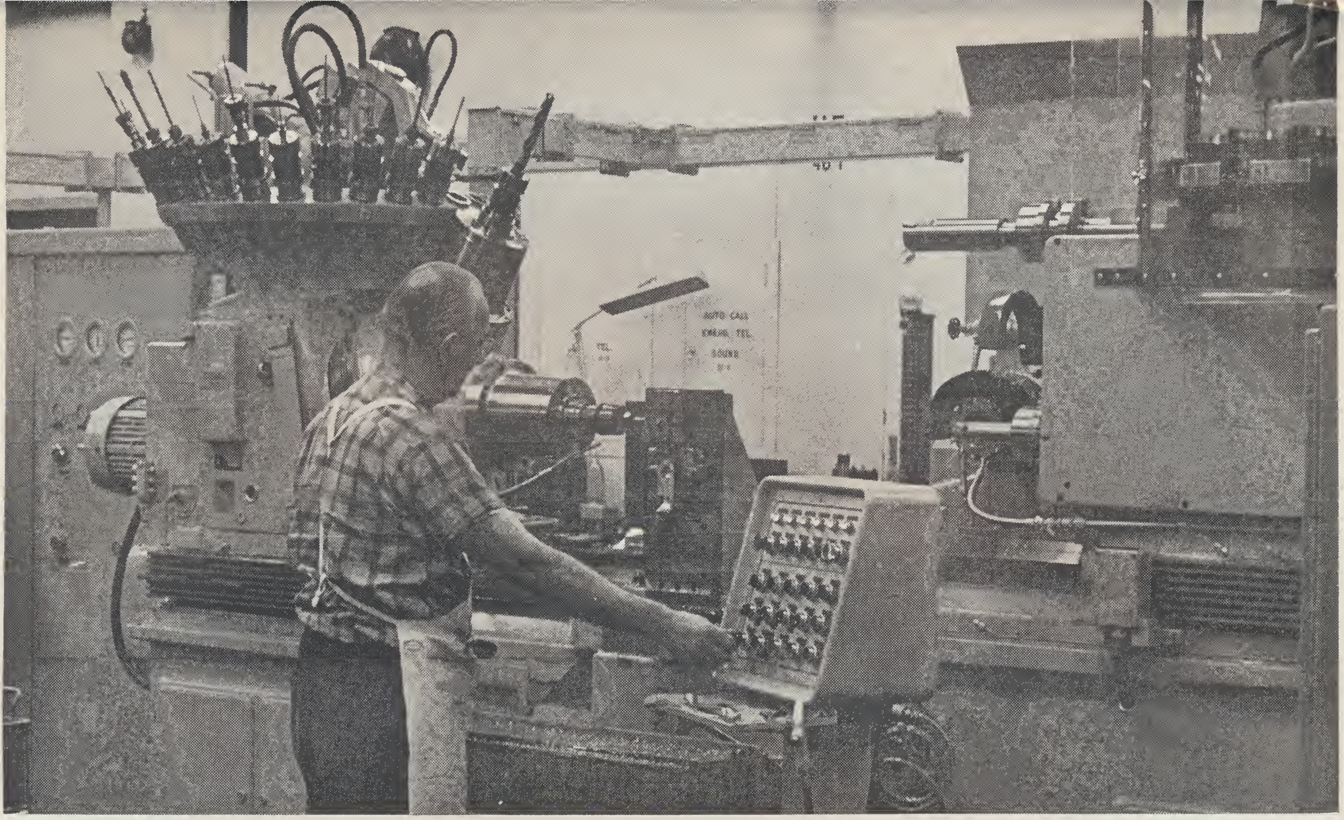


NC "machining center" contains universal head with tool changer (left), milling head (rear center) and boring head (right).

Metalworking's NC '63 Supplement

Multi-Purpose Machine —Job Shop in a Plant

Versatile "machining center" is paying for itself with savings in fixtures, inspection, scrap and machining time. Also, it's taking many expensive, one-shot jobs out of the model shop. Computer programming provides additional savings.

Numerical control achieves a long-standing goal of manufacturing engineers—completely machining a complex part with one setup on one machine under fully automatic control. Such a machine—an NC "machining center"—is providing spectacular advantages in machining precision castings at the Endicott, N. Y., plant of International Business Machines Corp.

After 5 months of two-shift operation with its new Hughes MT-3 "machining center" (the first unit purchased outside of the Hughes organization), IBM reports impressive savings in production time, tooling costs, inspection time and scrap.

Averaging results for the jobs run to date, here is how the MT-3 is paying off:

- 50% reduction in floor-to-floor time
- 75% savings in fixture costs
- 50% savings in inspection costs
- Scrap and rework almost nil
- Fewer short runs in model shop.

About 10% of the parts being run on the Hughes MT-3 are completely machined in one setup from the as-cast condition. About 75% are machined completely in one setup after a preliminary skim cut on a conventional miller for fixturing.

Floor-to-floor time has been reduced by about one-half on the average job. This saving reflects: (a) machining program controlled by tape—no time lost by the operator in checking machining instructions, blueprints, dimensions, etc., or positioning the work for each step in machining sequence; (b) automatic tool changing—the right tool is ready in the spindle when it's needed; (c) minimum of "cutting air"—tape enables cutters to approach work at maximum speed (150 ipm), then automatically decelerate at the minimum safe distance; (d) less handling time because of few setups.

Fewer setups mean fewer fixtures. Also, the fixtures that are employed are simpler and less expensive, since accurate tool positioning is provided by the control system rather than the fixturing.

Manufacturing engineer Arthur W. Camp, who has been closely associated with the MT-3, estimates that work-holding fixtures for the MT-3 cost at least 75% less than for conventional machine tools.

On five representative jobs, the

IBM's Vest-Pocket "Job Shop"

fixture costs for the MT-3 totalled $6,110 compared with $23,250 previously spent for conventional tooling. Mr. Camp points out that the figures for conventional tooling include only the cost of fabricating the fixture and that design time is charged to overhead. On the other hand, the fixture costs for the NC machine includes both fabrication and the cost of programming and preparing the control tape.

The parts being machined on the MT-3 are aluminum sand or die castings for brackets, supports, housings and similar structural parts for IBM computers, the main product of the Endicott plant. Lot sizes are relatively small: usually they range between 10 and 100 pieces; 50 pieces is typical.

Tolerances In Tenths

Machining tolerances are tight. In many parts bored holes must be within 2 tenths of size, distance between milled surfaces within 0.001 in. and hole locations within 3 tenths. Many of the critical dimensions are specified as statistical dimensions for statistical-quality-control purposes. This means that about 68% of the parts sampled must be within 50% of the allowable tolerance range.

IBM is finding that numerical control has reduced the size of the minimum economical production run. One-shot jobs of about ten pieces used to be run off in the model shop if permanent tooling would be too costly. Today it pays IBM to route such one-shot jobs on the MT-3 if the lot size is only four or five pieces.

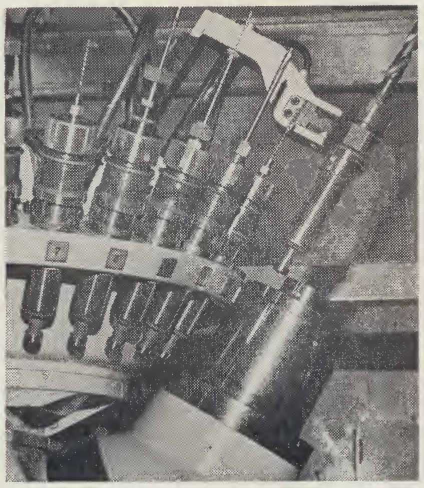
Another important area of savings is better quality and less scrap. IBM says that numerical control virtually eliminates the chance of scrap and rework once the control tape is proved out.

Savings in inspection time are another by-product of NC machining. Fewer parts need to be inspected to obtain assurance of accuracy and fewer dimensions need to be checked on the inspected parts.

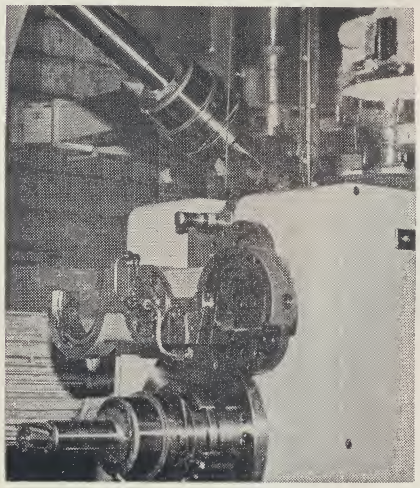
On the average, IBM inspects about 50% fewer parts per lot with no loss in quality assurance. In cases requiring 100% inspection, the sampling rate could be cut by much more than 50%.

In addition, the number of dimensions checked on inspected parts has been drastically reduced. Usually, just a few controlling dimensions are checked to confirm that the part is acceptable. Inspection time on some parts has been cut from about 60 min to 10 min or less.

"Each time a piece is moved to another machine to continue the machining operation," Art Camp commented, "is another chance for scrap. If a piece can be completely machined in one fixturing, it becomes part of the machine. Dimensional relationships remain constant and a big source of scrap is eliminated."



Next tool is loaded in idle spindle while other spindle is in cut. Spindles index.



Precision boring head has tool changer and magazine with 14-tool capacity.

Justified By Savings

The complete MT-3 center costs about $235,000, including transportation, installation, training, tool holders and adapters. Can such an investment be justified? The answer, says IBM, is "Yes."

As a matter of policy the company does not disclose its specific criteria for justifying any capital investment. However, they do say that a plant that has the same cost structure, volume and quality requirements can expect the MT-3 to pay for itself in 2 to 5 years.

Furthermore, IBM applied their usual payback requirements to justify the MT-3. They made no exception to "get NC into the plant."

The MT-3 was justified on the basis of a two-shift utilization. It soon will be scheduled for three shifts, so that the payback period will be shortened proportionately.

The MT-3 machining center consists of a basic machine and control, with additional machining heads available as options.

The basic elements are: (1) the universal head designed for drilling, tapping, light end milling and light boring (the head is equipped with an automatic tool changer and a magazine with a capacity for 30 tools); (2) the 18-in.-diam work table with controlled motions in the transverse and vertical axes and 16 rotary index positions; and (3) the Hughes NC solid-state positioning system that controls table and spindle motions, tool changing and all other machine functions.

IBM's version also has two additional machining units that are installed around the sides of the work table. One is a heavy-duty, 10-hp milling head with an 8-in. cutter capacity. The other is a 7.5-hp precision boring head with a 6-in. boring-bar capacity. The boring head is equipped with an automatic tool changer and a 14-tool magazine.

Tool changing is particularly fast

because the magazine rides with the head and because of the two-spindle arrangement. No time is lost switching tools in and out of the magazine because the next tool is being loaded in the idle spindle while the alternate spindle is working.

Computer Programming

Control tapes for the MT-3 are now being programmed on a 1620 computer with the help of Autospot, a programming language developed by IBM for NC positioning systems.

"The difference between computer and manual programming," said manufacturing engineer William F. Henry, who used both methods, "is like night and day. Computer programming is not only faster but, because it eliminates many tedious calculations, it also greatly reduces the chance of error in preparing the machining instructions."

As an example of how Autospot simplifies the programmer's task, he cited a part whose original manual program had been rewritten by Autospot. The program took about 100 hr to prepare by manual calculation and contained 395 individual instructions. With Autospot, the same program required only 20 hr and contained only 51 instructions.

A detailed description of Autospot is available from IBM (also see METALWORKING, May, 1962), but here are a few of its advantages:

Programs proper machining conditions: For each tool called for in the machining program, from a master tool list in its memory the computer automatically furnishes the appropriate speed, feed and coolant instructions on the tape.

Clearance envelope: From the part and tooling drawings the programmer establishes an imaginary envelope around the part, outside of which the tool can move freely without danger of collision. For every motion, the computer figures how far the slide must retract so that the tool clears the perimeter of the envelope.

Rapid approach limit: The programmer specifies how far from the work (usually 0.1 in.) the slide should shift down from rapid traverse to feed, The computer automatically computes this point for each tool used.

Aside from the foregoing type of "traffic" instructions, Autospot provides some invaluable short cuts for defining a series of positioning instructions. For example, to drill a bolt-hole circle, the programmer merely specifies the center, the radius, the number of holes and the angular spacing between holes (with skip-locations if any).

Repeat locations: If several operations are to be done at several locations (for example, drill, bore and ream six holes), the programmer writes their coordinate locations just once, and gives these locations a "Pattern Number." Thereafter he can program additional operations at this group of locations by calling for the appropriate pattern number.

Pocket milling: The programmer defines only the corners of the pocket, depth of pocket and number of steps-to-depth. The computer fills in the necessary positioning information to make the cutter machine out the pocket.

To use Autospot programming for the MT-3, IBM developed a post-processor routine. This routine is to be part of IBM's post-processor library and will be available to MT-3 users that have access to a 1620 computer.

Performance Test

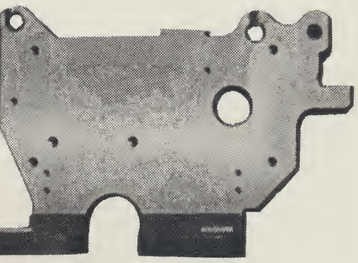
An interesting sidelight of the MT-3 installation is the special workpiece that IBM developed to test the performance of the machine. The test part is a hollow, rectangular aluminum casting measuring about 9 x 6 x 6 in.

The machining program uses 45 different tools. Except for some preliminary drilling, no tool is used twice in succession. This tests the accuracy of tool changing.

Locations of the bored holes are approached from different directions to test positioning accuracy.

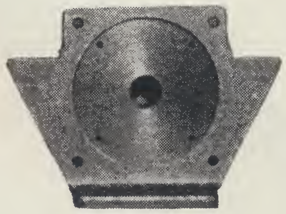
The heavy-duty milling head is programmed to remove ⅜ in. of stock in one pass to check the system at full-rated power. Also adjoining portions on the same surface are milled to the same depth with one heavy cut on one side and a succession of light cuts on the other. This checks the spindle's depth positioning and traversing accuracy under different loads. In all, the test machining tape contains 540 blocks of instructions.

Three Typical Parts



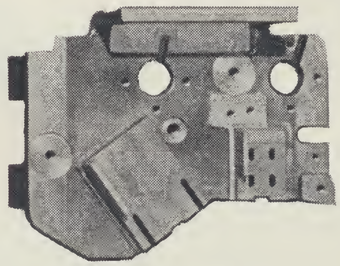
Carriage Support

	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	0.39	7.8	0.91
Tooling cost	$1,290	—	$5,200



Mounting Bar Support

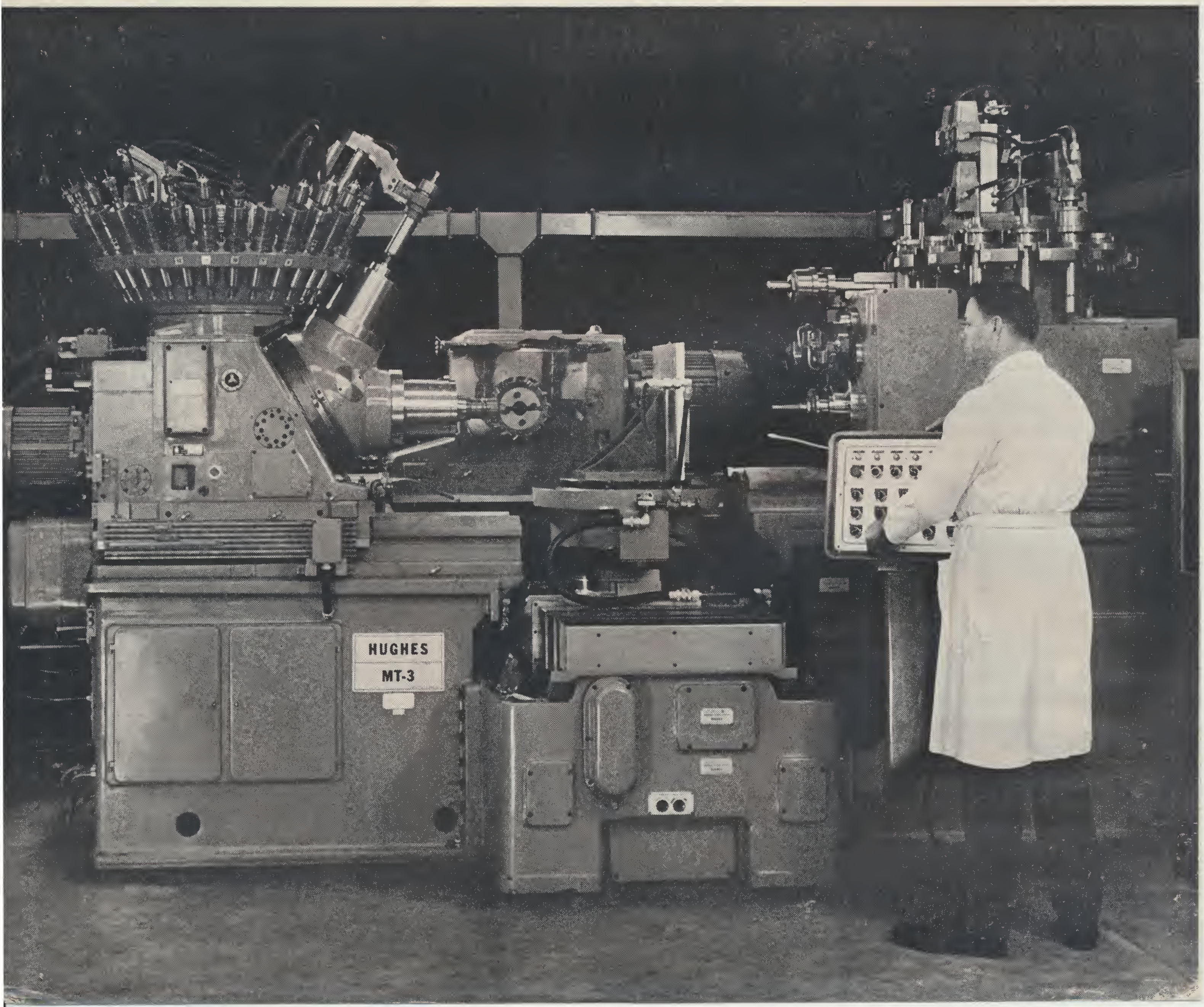
	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	0.42	10.7	0.71
Tooling cost	$1,550	—	$8,250



Retractable Head Platform

	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	1.1	23.6	yearly quantity does not justify tooling
Tooling cost	$6,620	—	

NC makes major savings in machine time and tooling costs over conventional machining, big time savings over model shop. Note job that couldn't justify permanent tooling. NC tooling costs include fabrication plus programming, conventional tooling, fabrication only.



HUGHES
MT-3

Basic Concepts Undergo Change At N/C Machining Center

The numerically controlled machining center is picking up some valuable information in its shakedown cruise.

One involves the question of using multiple spindles.

By R. H. Eshelman
Machinery Editor

▪ Are basic concepts in numerically controlled machining centers changing? The recent experience of a leading precision machine tool builder affords some significant insights to this question.

Will numerically controlled machining centers need multiple spindles to exploit full capabilities? Should heads and spindles be tailored to perform specific tasks, rather than for all around versatility?

Probably, at least for high precision work. That's the deduction of The Gleason Works, Rochester, New York, who specialize in bevel and hypoid gear manufacturing equipment.

A Match in Precision. To pay off, numerically controlled machining must, and in most cases can, match the precision and other specialized capabilities of conventional equipment.

The Gleason Works has many complex parts to manufacture for their line of high precision, gear manufacturing machines. As a result, they had to constantly reevaluate the economics of lot sizes, machining methods, inprocess handling and parts storage.

For the focal point of their piece-parts machining operation, they recently chose a three-spindle type machining center. And it's paying off, notes P. F. Barker, Manager of Industrial Engineering at Gleason Works.

H. J. Terhaar, manager of Gleason Works' Machine Division, points out precision bore requirement to P. F. Barker, manager of Industrial Engineering.

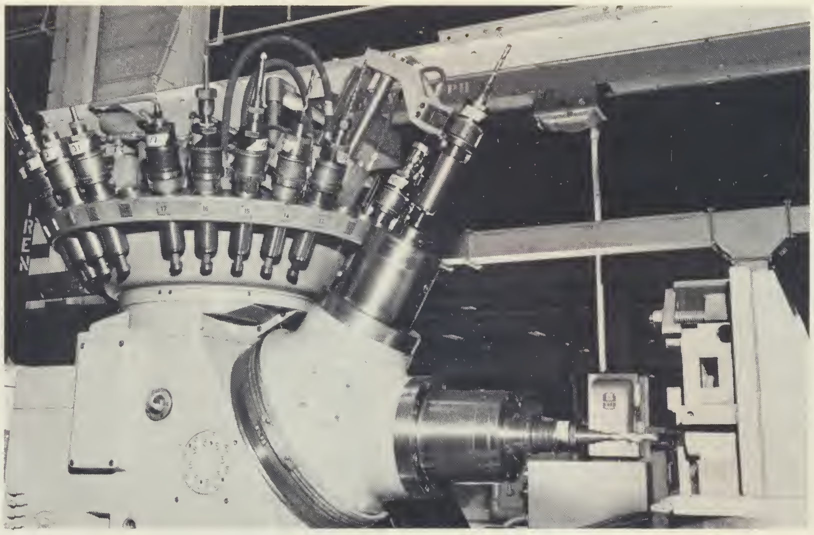
"The big impact a machining center makes in any shop, including ours, lies in the many jigs and fixtures it eliminates, reduction in inventory, handling of parts from one department to another in the plant, and reduction of lead time from design to assembly."

Machine Features. All of these items are of utmost importance. "But," he advises, "on specific production parts, design features of this machine proved very attractive, namely, three spindles, one for milling, one for boring and one for drilling."

Mr. Barker points out that the desired characteristics of these three operations cannot be designed into one spindle. So three separate spindles provide an important advantage.

"Virtually all production parts will ultimately be done on N/C machines," according to T. F. Klem, assistant manager of Process and Standards Engineering. "And the toughest nuts are going to the machining center."

Part in Question. An example is an index housing. A drill jig on this part would be exceedingly expensive — bushings alone, estimated to cost over $400. In addition, there are costs, continuing for the life of the part, repairs on the jigs and part fixtures, in-plant handling, maintenance and storage.



The numerically controlled machining center is equipped with three building block-type heads. Each one of the heads has its own spindle and motor.

The machining center can usually handle such parts at substantial savings in one setup, over conventional machining, and without complex tooling. Only simple work holding fixtures are needed.

On parts with a variety of drilling, tapping, reaming, boring, face milling and pocket milling or picture framing, as many as a half dozen operations and setups have been eliminated. The percent of direct labor costs saved on five representative parts ranged from 49 to 59.5%.

Building Block Heads. Gleason's N/C machining center is a Hughes MT-3. This is equipped with three building block-type heads, each with its own spindle.

The first has a universal spindle design for drilling, tapping, reaming and light milling (with minimum side load forces), and even some light boring. It has a 7.5 hp motor. The spindle bearings are designed specifically for these operations.

As with the other spindles, this is a horizontal type spindle. It is equipped with a vertical tool changer on top of the head, where 30 tools are in live storage for automatic quick change. Accomplishing the tool change by turret rotation takes only three seconds.

Accordion-Type Collet. The used tool is changed from the spindle to its proper magazine storage location during the cutting cycle. Use of an accordion-type collet, with positive retention of the tool, is an important precision factor. The second head has a spindle for heavy duty milling and has a 10 hp motor.

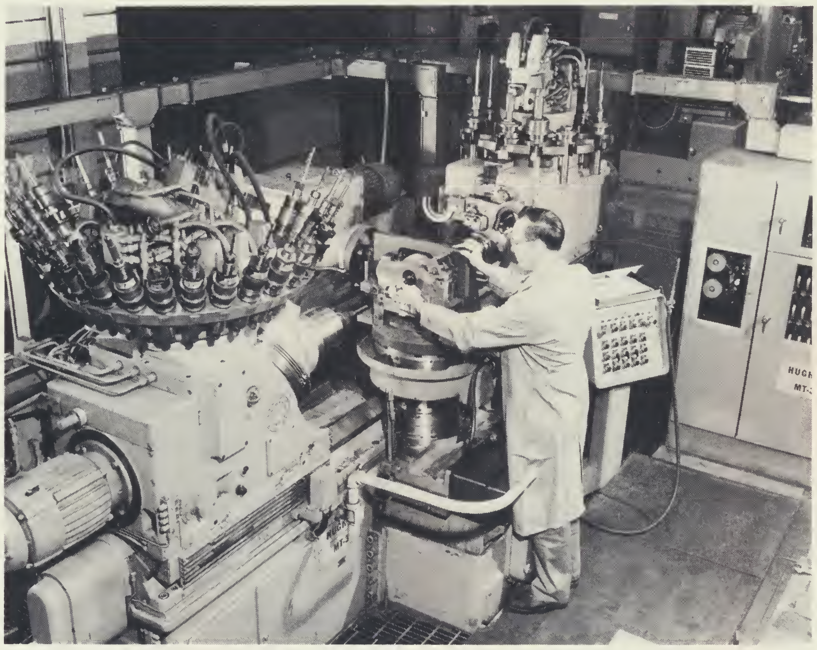
The third head has a precision boring spindle and also located above is a vertical tool holder which automatically stores and changes up to 14 tools. This spindle may also be used for light milling and spot facing. It has a 7.5 hp motor.

The machine's hydraulic and lubrication system is equipped with a ±1° temperature control which aids in maintaining its precision tolerances.

Aerospace Success. This type of machining center has previously registered success in the aerospace industry working primarily with nonferrous materials. However, machine tool piece part work may give this machine-type concept its sternest test.

At the Gleason Works, up to 95% of the parts going on to the Machine Center will be machine quality cast iron. In addition, many of the tolerances will be in the 0.0002 in. range.

The policy at Gleason is to buy machines and place them into production immediately. The Industrial Engineering group has found that previous experience afforded little help with the new multi-spindle concept, so it has



On this head 30 tools are kept in live storage. Any one of these tools can be changed automatically by turret rotation in a period of only three seconds.

Final tool setting for the next job is done while the current one is being run.

had to pioneer new systems and procedures for loading, scheduling and programming.

After trying a number of methods, a satisfactory technique was developed to take advantage of the maximum capability of this installation.

Programmed by Computer. Because of the critical location of this unit in the parts manufacturing system and the short cycling time, fixturing, tools and programs must be coordinated and ready at the same time. Autospot is used for programming all parts. This computer programming system has simplified the part programming.

Pre-set tooling is used. Tools of specified lengths are assembled in the tool crib and are set to final dimensions at the machine before being placed in the tool storage rack.

The operator actually is able to set up tooling for the next job while the current one is being finished. Thus, set-up time and machine downtime for change over are held to a bare-bone minimum.

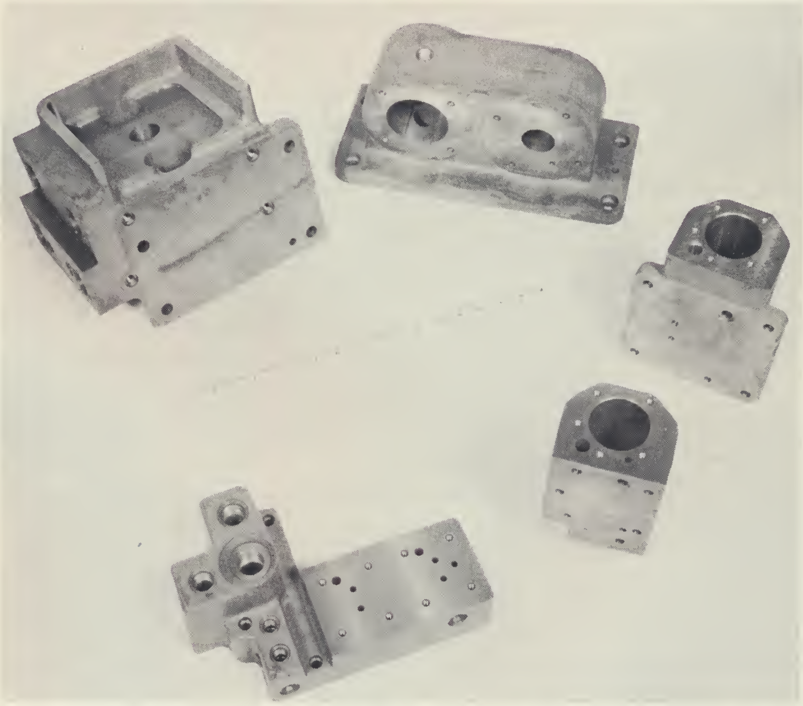
On an average, the industrial engineers prefer to run through at least 20 piece lots. But they have scheduled job runs up to 150 to 200 parts and are willing to put in quantities down to 10 complex pieces.

Big in Manufacturing. Impact of this machine has loomed big on parts manufacturing orders. A downward revision in their economic ordering quantity concept has resulted.

This method applies an efficiency formula to ordering and storing the ideal number of any particular part prior to assembly. With the efficient use of an N/C machine and minimum tooling and workholding, it has been possible to cut order quantity as much as 18% on typical piece parts.

Another benefit provides for a speeding up of engineering changes on special orders or new and improved design of parts.

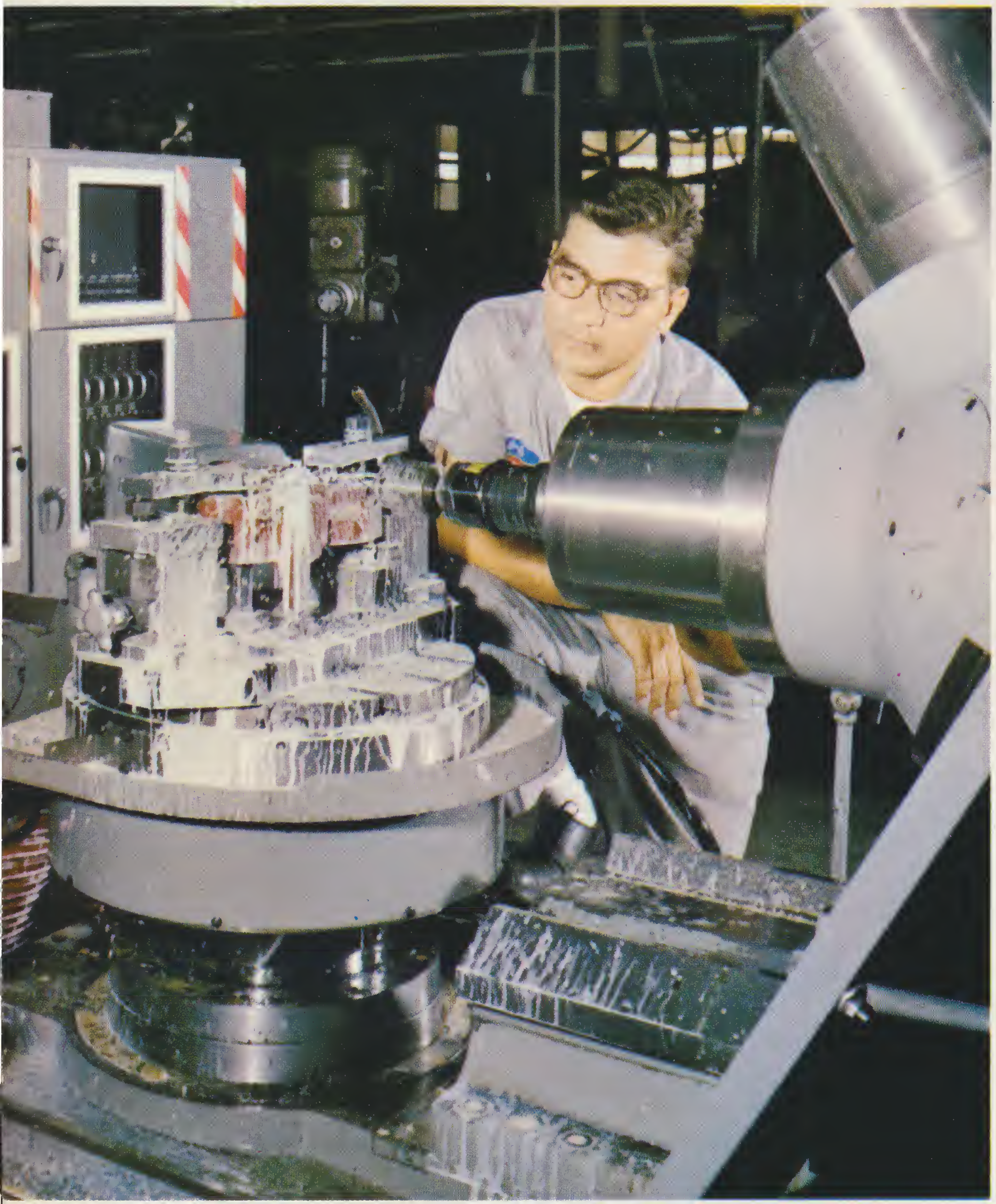
In the utilization of this machine capability, the plant is subjecting not only this machine to a more rigorous schedule but probably most of the equipment in the plant. They operate this one six days a week, three shifts a day. ■


The percent of direct labor costs saved on these five representative parts ranged from 49 to 59.5%. Only simple work-holding fixtures are needed.

N/C and the small company

Its first machining center nets big cost reductions for Milton Roy Co. Thorough planning and home-grown talents help start immediate payback by $250,000 machine tool

Joseph J. Deckert,
Manufacturing Manager
Mechanical Products Division
Milton Roy Co.



Set up and running production on schedule, the machining center is the final step in the total plan, which includes competitive analysis, product redesign, management support, vendor assistance and close co-operation by Engineering and Production

• When a small company with only 150 employees moves into numerical control for the first time, with an investment of a quarter of a million dollars, and finds no discomfiting surprises, then it's proof the groundwork was well laid and the planning for n/c thorough.

This is the experience of Milton Roy Co., Philadelphia producer of fluid pumps and instrumentation, despite the nerve-shattering hearsay that abounds concerning the difficulties to expect from n/c, such as programming bottlenecks, maintenance nightmares, and generally high machine downtime.

If the company's manufacturing engineers were in the dark at all about n/c, it was that while an abundance of information was available about aluminum as a workpiece material, not enough case history data could be obtained on cast iron, 316 stainless steel and other alloys with which the company works. Consequently, some small doubt lingered about the inherent rigidity of n/c units.

But, on looking back to that August day three months ago when the unit, a Hughes MT-3 machining center, began running production, one wonders what the fuss was about. Tool, fixture and setup cost reductions are an indicated 75 per cent below conventional machining. In addition, housings for special pumps now can be produced on the machine instead of in the model shop, greatly reducing delivery time and cost. Other advantages include shortened lead times by months due to the simplification of fixturing, and tighter quality control due to the increased accuracy of dimensional relationships by holding parts in a single work fixture.

Management's interest and enthusiasm for the n/c project is best expressed in a way not found on any justification sheet. Said President Robert T. Sheen: "We will be giving our customer the fastest possible delivery by assembling our pumps from off-

the-shelf components and a bank of stock housings, the latter made possible by the speed and flexibility of n/c."

What paved the way to the orderly acquisition, installation and running-in of n/c was the completeness of justification procedures, including a competitive analysis of equipment; a plan to standardize and redesign the pump line for n/c machining, to minimize inventories, eliminate secondary operations and minimize the frequency of setups; and the close cooperation of the machine tool builder who assisted in programming and in proving tapes among countless other helpful tasks initiated in the company's behalf.

No Experiments, Please

The Milton Roy Mechanical Products Division, where the n/c machine is installed, accounts for roughly $5 million of the company's $6-to-7 million total volume of sales of products ranging from pumps to sophisticated instrumentation for analytical, pilot plant and medical fields. It may seem a paradox, therefore, that the company went into n/c "big", ignoring the oft-heard suggestion that it start out on a small scale and get its feet wet with, say, a $20,000 investment. Due to the strange facts of economic life, however, the company couldn't "afford" the smaller investment but could exceed that amount by twelve times for the reason that it buys for a specific need, not just for experimentation.

Evaluation Includes Transfer Line

The investigation into n/c began as part of a broad-based study on new equipment acquisitions. The company had just introduced the first of a new line of pumps intended to replace some industry standbys. The purpose was to improve the product with advanced features while minimizing the engineering and manufacturing expense involved, which is simply common-sense economics.

It was necessary, first, to incorporate the great variety of sizes and types of pumps produced through the years into a range of standardization which offered the same pumping capabilities to the consuming industries but reduced the number of actual designs manufactured to a relative few. N/C was simply the logical extension of the broad standardization program being carried out.

Initial equipment investigation took into account several possibilities with the objective of finding the one most suitable which would afford the best pay-out for the company. The spectrum examined ran from direct replacement of conventional machines through the n/c machining center concept to the ultimate stage of Detroit or transfer-type automation.

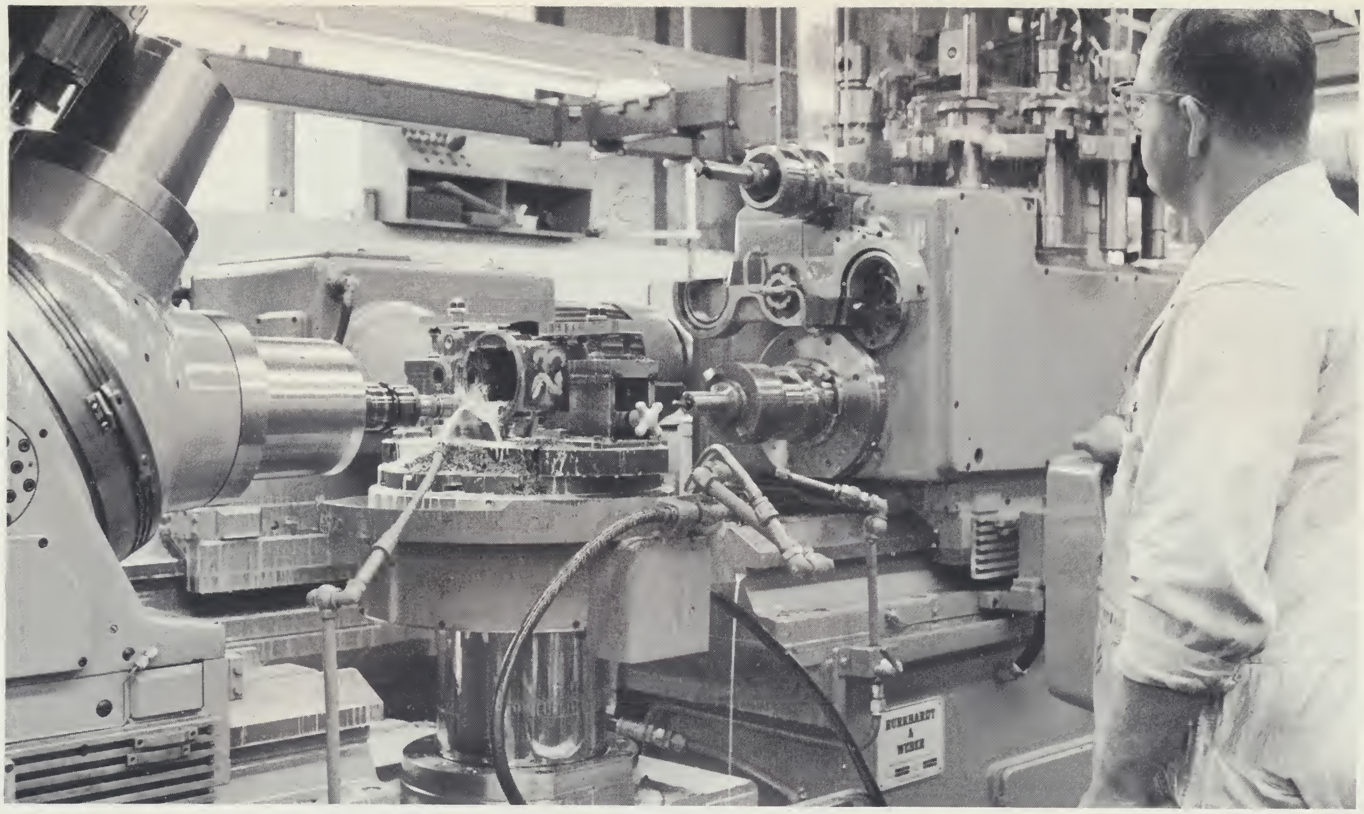
Early in the investigation, it became apparent that due to the limited product lot sizes (200 to 1700 housings per year for each of five pump configurations) envisioned under the standardization program there would be no advantage in the direct replacement of the conventional type machines in use at the time. Replacement, therefore, was discarded as a possibility and attention was centered on n/c and the transfer line.

It was thought at first that the higher

N/C MACHINING CENTER EVALUATION
(Partial List)

MACHINE FEATURE		ASSIGNED RATING VALUES	MT-3	MACH A	MACH B	MACH C	HUGHES MT-3 SPECIFICATIONS
X AXIS (cutting length)	Overall						24 in.
Y AXIS (cutting length)	Mach.	20	12	20	18	5	12 in.
Z AXIS (cutting length)	cap.						19 in.
INDEX ACCURACY		20	10	10	20	10	±10 secs.
NUMBER OF SPINDLES		20	20	7	7	7	3
SPINDLE HORSEPOWER		15	10	15	12	5	7-1/2 & 10
SPINDLE DRIVE TO TOOLHOLDER KEYED		20	20	20	20	20	yes
SPINDLE SPEED RANGE--RPM		20	20	16	15	5	40 to 4000
NO. OF AUTOMATICALLY CHANGED TOOLS		20	20	18	15	5	45
MAX. DIA. OF TOOL WITHOUT DELETING OTHER TLS.		20	20	15	15	5	6 by 18 in.
TOOL CHANGE TIME		20	20	10	8	18	0 or 3 or 10 sec.
TRAVERSE HOME POS. REQ. TO CHANGE TOOLS		20	20	5	5	5	no
FEED RANGE INCHES PER MINUTE		20	18	13	20	7	.5 to 75
RAPID TRAVERSE RATE, IN. PER MIN.		20	15	20	20	20	0 to 180
PALLET CHANGER		20		20	20		no
WAY CONSTRUCTION		20	15	20	18	17	cast iron
TYPE CONSTRUCTION		20	20	18	10	5	trav. hds. & tabl
PROGRAMMING		20	20	15	18	10	incremental
RESOLUTION (smallest command mach. accepts)		10	5	10	8	5	.0001 inch
POSITIONING ACCURACY		20	10	20	18	10	±.001 in.
REPEATABLE ACCURACY		20	18	20	8	15	±.0003 in.
CONTOURING WITH THIS CONTROL		10	--	10	5	--	no
AUTOMATIC TAPE REWIND		15	15	--	15	15	yes
POSITION READOUT		20	20	18	18	18	command & actual
FEED RATE OVERRIDE		20	20	5	5	5	100% to stop
ZERO OFFSET		10	5	10	10	8	no (mech. ±.020)
PERSONNEL TRAINING COSTS			$1,825	$3,215	$1,287	$925	
TOTAL		908	760	633	646	431	

(The following departments concurred unanimously on selection of MT-3: Manufacturing, Production Control, Tool Engineering, Industrial Engineering)



Cast-iron pump housing requires only two handlings and takes little more than a half-hour to process. Previously, 2.75 hours, floor-to-floor, irrespective of handling, were needed on a boring mill, turret lathe and five drill presses

←
N/C evaluation chart lists important features and specifications (about half the actual number are shown, here) of four machining centers. Each center measures against assigned point values and is rated accordingly. The chart is one of several factors that figured in final selection of the MT-3

base cost for the transfer line would be offset by greatly improved cycle times in machining and, hopefully, the amount of time necessary for change-over would be absorbed. However, this became an unrealistic area for further consideration, owing to the fact that again lot sizes are relatively modest and that flexibility and change-over time are major factors. This left the n/c machining center as the most likely production method for consideration.

In late 1963 and the first six months of 1964, extensive investigations carried on with various manufacturers of this type of equipment included long sessions with their representatives and trips to their plants. Eventually, the field narrowed to three potential vendors of equipment considered to be the optimum as to productivity and economy for Milton Roy's needs. These three manufacturers were asked for guaranteed estimates of the cycle times for seven basic pump parts which were considered the primary output of the n/c machine.

(All the while, management was kept abreast of events by an evaluation and justification manual prepared and kept up to date by Manufacturing. Since Milton Roy is a small company, matters of this magnitude are generally followed closely by top management, whose enthusiastic support and cooperation were offered to this project from the outset.)

The investigation at this point narrowed the field to two types of n/c equipment. At this time a formal presentation was made to the board of directors. This consisted of a detailed outline of the procedures and evaluations that had been made up to that time and included films of the two machines in action. Following the meeting with the board, Manufacturing proceeded to a final decision leading to the purchase of one machine. To accomplish this, return trips were made to the two manufacturers and the machine with specifications that appeared to best meet company needs was selected.

Work Out the Details

The choice was the standard Hughes MT-3 configuration with three machining heads, including a precision boring head and a rotary indexing table which feeds vertically and horizontally. At the same time final arrangements included the requirement that tooling details, programming and tape preparation and prove-out should be done for seven basic parts by Hughes. One of these parts was selected as the acceptance part and firm commitments were made that this part should be not only tooled and programmed but that the particular work piece should be prepared and run at the Hughes plant for acceptance test prior to shipment. This test was to be repeated after the machine's installation in Milton Roy's plant. It was understood that the particular part would not only be machined to the drawing specifications, but also within a guaranteed time given by the vendor's organization.

At the time of purchase, Manufacturing

and Engineering collaborated on detailed parts changes to facilitate manufacture by n/c. These changes, primarily aimed at reducing cycle times, included making hole diameters and thread sizes more uniform to reduce the frequency of tool changes on the machine. Currently, changes continue to be made as the need arises.

Delivery, promised for May of 1965, actually took place on May 7. Prior to actual shipment, details concerning foundation and other mounting information were provided by Hughes and a suitable foundation was constructed at the plant. On the fifth week, the machine was installed and running. Approximately three weeks after delivery, the acceptance part was being run.

Following acceptance, a programming specialist arrived from Hughes to work with company programmers on proving the programs and tapes for the balance of the parts. This was completed at the end of June and trial runs were started on July 5, 1965.

First Results: Inventories Down

With the shorter setup times and cycle times of n/c, inventories are being sharply reduced. Previously, the longer lead times occasioned by conventional machines, with the lag from one machine to another, meant that long runs had been the norm. Now, however, the application of Economical Order Quantity formulae understandably reduces the lot sizes, and eventually, the company expects to reach a point where it can approximate its actual needs in advance of the actual month required and run no more than this quantity. The result is a reduction in average inventory both in stores and in process.

Needed: Electronics Training

The advent of n/c brought with it special requirements for maintenance, industrial engineering, programming, and tool room operations. Though the company is still in the process of adjustment, all the changes have been accomplished with the use of in-plant personnel, who required special training but were confidently up to the requirements. The company doesn't feel it is unique in finding within its organization the people qualified to learn the new skills. Instead, it feels that these skills are more likely found within a small company than in a large one because personnel frequently double up on duties and perform varied tasks rather than performing along the lines of limited specialization often found in larger companies.

A horizontal boring mill operator was the first person selected to man the n/c machine primarily because of his analytical approach to problems and the fact that he had a broad background in cutting tool preparation and maintenance.

For programmers, two industrial engineers were picked who had been handling methods and standards work. They were sent to the Hughes factory for a two-week training program and became well adapted to this new skill.

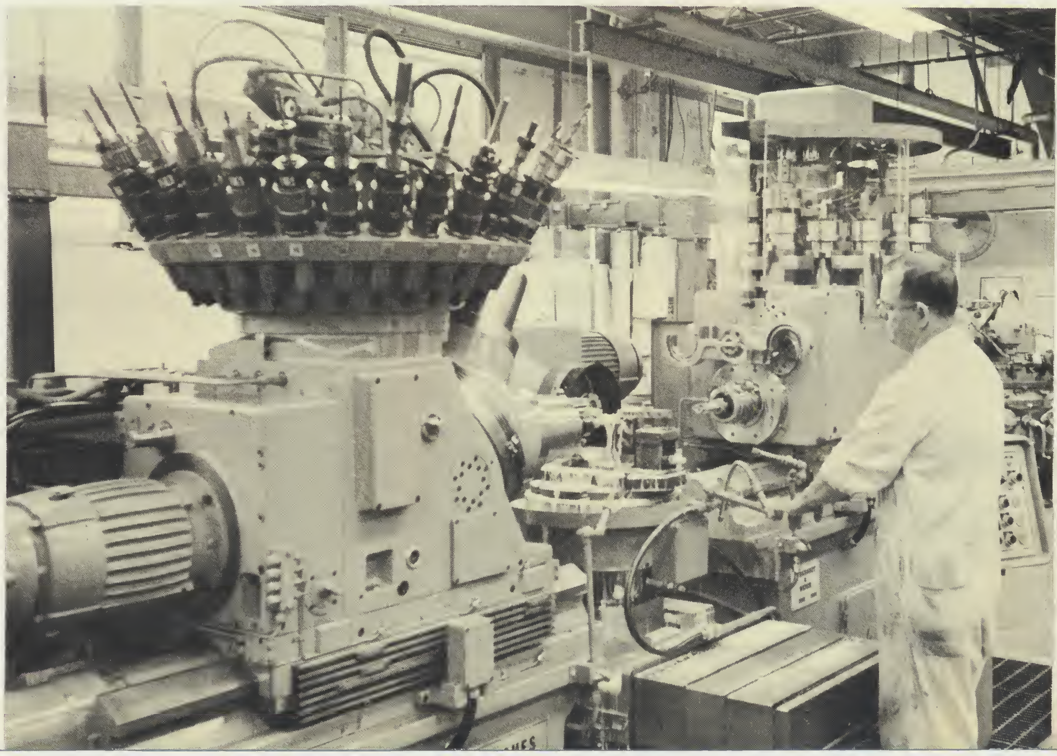
On the other hand, the maintenance electrician was highly skilled in electrical and mechanical maintenance but had no electronics background. This, admittedly, is a problem that awaits solution with further electronics training before the company is completely self-sufficient in this area. In the meantime, vendor service personnel are readily available should a serious problem arise.

Tool Up By Degrees

To limit the initial expense for tooling, only those tools, holders, cutters, and adapters needed to handle the basic parts envisioned for the machine were selected. No attempt was made to buy perishable tools beyond immediate requirements. The general approach is to have sufficient tooling on hand to prepare the following job while a job is running. In coming months, it's planned to have enough tools on the shelf pre-set and stored for every standard job going across the machine.

In the area of preprogramming, of tool design and the tooling for several parts, initial thinking was concerned primarily with the need to move into production quickly. There was no time to go through a learning curve. Milton Roy now believes they should have requested that initial programming be limited to the acceptance part by the vendor. Added efforts would be done in-house since the company would be in a better position to know and understand its particular problems and how best to adjust to them.

The n/c project owes much of its success to enthusiastic teamwork displayed by Engineering and Manufacturing in their mutual desire to make the project "go". Most of all, management not only got on board to encourage the success of the enterprise but went out of its way to facilitate design changes to accommodate the product to n/c manufacture. ■



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